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Evaluation of two sugar beet cultivars (*Beta vulgaris* L.) for growth and yield under drought and heat conditions

A thesis submitted in partial fulfillment of the
requirements for the degree of
Doctor in Agriculture

Submitted by
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Assiut / Egypt

2004

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To my father in spirit whom I always remember and to my mother and dear sisters for their love and to my wife Mervat who helped me to finish this work and last to my daughter Rana that I wish her a good future.

1 Introduction

Sugar beet is a specialized type of *Beta vulgaris* cultivated for sugar production. It was developed in Europe at the end of the eighteenth century from white fodder beet, which was found to be the most suitable alternative source of sugar to tropical sugar cane. It is a biennial plant which stores up reserves in the root during the first growing season so that it is able to over-winter and produce flowering stems and seeds in the following summer. Sugar beet is a short-term crop of about 6 months grown in temperate regions of mainly the northern hemisphere for sugar production. Fresh root yields range from 50-60 tonnes/hectare, sugar concentrations of the roots average 18.7% and sugar yields are 9-11 tonnes/hectare. Estimated world sugar production is 124.4 million metric tonnes for 2000-01 of which about 30% (37.3 million tonnes) is from sugar beet (USDA, 2000). The sugar beet plant is commercially and physiologically interesting because of its ability to store sucrose at high concentrations within its root. Although the developmental physiology of the plant has been studied, little is known of the factors that govern the sugar content of the root or the physiological changes that cause it to vary (Milford and Thorne, 1973). In recent years, improvements in sugar concentration of sugar beet and development of more heat-tolerant varieties has created interest in growing sugar beet in areas currently growing sugar cane for sugar production.

Potassium is an important univalent cation generally recognized to be indispensable for growth of all plants. It is characterized by high mobility in plants at all levels within individual cells, within tissues, and in long-distance transport via xylem and phloem (Marschner, 1995). Potassium, one of the major plants nutrients, is required by plants in amounts similar to or greater than N. In plants with only a moderate or even inadequate potassium supply the concentrations are highest in the younger, actively growing parts, owing to the higher metabolic activity. Potassium has various functions in turgor-related processes, such as cell extension. It is a highly mobile carrier of positive charge and it is important for enzyme activation, photosynthesis, and respiration (Huber, 1985). According to Mengel and Haeder (1977) potassium plays an important role in the transport of metabolites in the phloem, particularly with respect to transport into storage tissues. Potassium ions increase the

synthesis of carbohydrates with high molecular weights, also in storage tissues. Plants that accumulate large reserves of protein, carbohydrate and fats in their storage tissue therefore have high potassium requirements (Evans and Wildes, 1971; Mengel, 1999). The rate of photosynthesis is high in plants receiving adequate amounts of potassium, probably due to the positive effect of K^+ ions on the transport of the products of photosynthesis, because the faster the assimilates are removed, the better the utilization of photosynthetic capacity in the leaves. Adequate K^+ nutrition frequently thickens cell walls thereby providing more tissue stability and improving the resistance of crops to lodging, pests, and diseases (Beringer and Nothdrutt, 1985). In sugar beet, K^+ plays an important role in the tolerance of water stress. It is the most abundant cation in the cytoplasm. Potassium and its accompanying anions make a major contribution to the osmotic potential of cells and tissues of glycophytic plant species. For various reasons, K^+ has an outstanding role in plant water relations (Hsiao and Läuchli, 1986).

The question of whether Na^+ can replace K^+ in physiological processes in the plant is not only of academic interest but also of practical importance in relation to fertilizer application (Mengel and Kirkby, 2001). It cannot be denied that the actions of Na^+ and K^+ are closely associated. This is also apparent from their co-operation in relation to deficiency symptoms. In some crops Na^+ has the capacity to prevent or to reduce considerably the occurrence of K^+ deficiency. On the other hand, above a certain level of K^+ fertilization, NaCl is more effective than KCl in increasing the yield of sugar beet, if calculated on a chemical equivalent basis. K^+ and Na^+ have synergistic or antagonistic effects, depending on the amounts of each of these elements present in the soil (Marschner, 1995). The effect of Na^+ on growth and metabolism depends upon the plant species: this is reflected in the classification of plants into so-called “natrophilic” and “natrophobic” species (Hampe and Marschner, 1982). Sugar beet plant is a natrophilic and chlorophilic crop and positive effects of Na^+ applications on yield were observed when K^+ was sufficiently supplied (Scharrer and Kühn, 1958). The reason for the beneficial effect of Na^+ has been related to an improved drought resistance when the water supply is limited and stimulation of assimilate transport into the beet root (Marschner, 1995).

The extent to which K^+ can be replaced by Na^+ in metabolic processes varies with plant families and species. Within the family of *Chenopodiaceae*, this replaceability is generally high (Lehr, 1953; El-Sheikh et al., 1967). In sugar beet, Na^+ can replace K^+ to a large extent and a specific growth-stimulating effect, which differs between genotypes within this species, was observed (Marschner et al., 1981 a). In less specific processes, such as raising cell turgor, some replacement is possible. The extent to which substitution can occur, however, depends much on the uptake potential for Na^+ (Marschner, 1971). In halophytes, the role of K^+ in osmotic adjustment of the vacuole is largely replaced by Na^+.

In sugar beet as a salt-resistant crop species similar steep inverse Na^+/K^+ gradients between old and young leaves are maintained as is typical for halophytes. High K^+ but low Na^+ concentrations in young leaves and reproductive organs are achieved by a general low xylem import of both K^+ and Na^+, but high phloem import of K^+ from mature leaves (Wolf et al., 1991). Harvey and Dutton (1993) demonstrated that the high concentrations of K^+ in beet limit the proportion of sucrose that can be extracted from the beet as crystalline sugar during factory processing. In this respect, K^+ has a greater effect than Na^+, α-amino-N compounds and the other major non-sugar "impurities" in beet.

The effects of water stress on physiological processes have been reviewed. Many important physiological processes such as leaf enlargement, stomatal opening and photosynthesis are affected by a reduction in leaf water potential (Jones and Turner, 1978). For most plants the maintenance of growth and function depends on maintaining a relatively high water content in the protoplasm. Drought-tolerant plants can use several mechanisms to adapt to water stress. These include reduction in water loss by increased stomatal resistance or increased water uptake by the development of large or deep root systems (Parsons and How, 1984). Mechanisms that tend to promote drought tolerance by maintaining turgor include osmotic adjustment, a decrease in cell wall elasticity or a decrease in cell size. The solutes that accumulate during osmotic adjustment include sugars, amino acids, organic acids, proline and glycine betaine (Munns and Weir, 1981; Hanson and Hitz, 1982).

In the Mediterranean region, adequate sugar beet production requires supplementary irrigation, but in recent years drought stress has become a major constraint to sugar beet cultivation even in Northern Europe, causing serious reductions in productivity (Jaggard et al., 1998; Pidgeon et al., 2001). Also, sugar beet tolerates mid and late-season plant water stress and this characteristic makes sugar beet a suitable crop for production with "limited" irrigation; i.e., an irrigation amount less than that required to fully satisfying evapotranspiration. Water stress will almost invariably decrease fresh root weight, but sucrose concentration, on a fresh weight basis, can be increased by dehydration of the root due to water stress. These effects on yields were mainly caused by dehydration of the beet tops and roots so sucrose production was scarcely affected even though only 70% of the normal irrigation water was applied. Wittenmayer and Schilling (1998) showed that sugar beet plants respond to drought stress by an increase in tap-root proportion in relation to whole plant dry matter. The underlying cause of this mechanism is still unknown. Nevertheless, there is good evidence that drought-induced ABA plays an important role in mediating many adaptive responses of plants to drought stress (Davies et al., 1990 and 1994; Duggan et al., 2000). Growing season environments may be characterized by the limitations imposed by stress at different stages of crop development. Drought stress has been shown to retard the formation of the yield component that is most actively developing at the time of stress (Aspinall, 1984; Entz and Fowler, 1988).

Richter et al. (2001) found that drought stress is the major cause of yield loss on sugar beet in the UK. It causes an average annual yield reduction of 10% (Jaggard et al., 1998) and in very dry years it decreased yields by as much as 50%, corresponding to 4 t sugar ha^{-1}. Improving drought tolerance of commercial varieties of beet is a promising approach, but sugar beet breeding is long-term (≅15 years) and expensive. Breeding companies need to be assured that the problem is widespread and likely to persist. Therefore, there is a need to asses the extent and complexity of the water stress problem in sugar beet production throughout Europe, now and in the future. Recently, Bnhassan-Kesri et al. (2002) reported that environmental stresses, in particularly drought stress, represent the main limiting factors of plant cell growth. Drought stress induces several effects including reduced cell division and growth rates.

The inhibition of stem expansion together with changes in leaf water content differs among species. However, leaves, which play a central role in gas exchange, are strongly affected by drought stress. Major effects are stomatal closure, inhibition of thylakoid-mediated electron transport and membrane damage (Bohnert and Shevelena, 1998).

The K^+ nutritional status has a great influence on the water use efficiency of several plants as mentioned before. Na^+ can substitute K^+ in a major function but little is known about the absolutely limiting processes during such a substitution in sugar beet. To investigate this problem, several experiments in soil and nutrient solution were conducted.

2 Objectives

The objectives of this study were to investigate, understand and identify limiting processes which are most affected by the substitution of K^+ by Na^+ concerning the sugar yield of two cultivars of sugar beet in soil culture and nutrient solution experiments. In addition, the effects of drought and heat on the growth and storage of sugar in two sugar beet cultivars were also investigated.

The objectives of the present work are:

- to evaluate the effect of K^+ and Na^+ fertilization on growth and quality of two sugar beet cultivars grown in soil under natural conditions.
- to determine the effect of water stress and substitution of K^+ by Na^+ related to the growth and water relations of two sugar beet cultivars grown in soil under natural conditions.
- to evaluate the effect of drought and heat on the growth and sugar storage of two sugar beet cultivars grown in soil in growth chambers.
- to evaluate the effect of K^+ substitution by Na^+ on the growth of two sugar beet cultivars cultivated in nutrient solution under natural conditions.
- to determine the effect of Ca^{2+} deficiency on the growth of sugar beet plants grown in nutrient solution in growth chamber.

3 Material and Methods

The soil and the nutrient solution culture experiments were conducted with two cultivars of sugar beet (*Beta vulgaris* L. cv. Evita and cv. Sofie).

3.1 Soil experiments

3.1.1 Evaluation of the effects of K^+ and Na^+ fertilization on growth of two sugar beet cultivars grown under natural conditions (Experiment 1)

This experiment was carried out in big Mitscherlich pots with 15.0 kg Kleinlinden soil for each pot. The soil characteristics are presented in Table 1.

Table 1: Characteristics of Kleinlinden soil.

Parameter	
Sand	32.3%
Silt	45.0%
Clay	22.7%
pH ($CaCl_2$)	6.3
CAL-K (mg K kg^{-1} soil)	47.4
CAL-P (mg P kg^{-1} soil)	6.5
CEC (cmol kg^{-1})	11.8

The Kleinlinden soil is a subsoil (40-90 cm) from a brown soil derived from loess. The CAL-extractable K and P are relatively low, but such concentrations are suitable for K and P fertilization experiments.

The soil was mixed with $MgCO_3$, $Ca(H_2PO_4)_2$ + $CaSO_4$ (superphosphate), NH_4NO_3 and H_3BO_3 at rates of 0.133, 1.91, 0.38 and 0.003 g kg^{-1} soil, respectively. Six treatments i.e. 2.5 g KCl; 5.0 g KCl, 2.0 g NaCl, 3.9 g NaCl, 2.5 g KCl + 2.0 g NaCl and 5.0 g KCl + 3.9 g NaCl were used. The NaCl application was equivalent to the KCl supply. Factorial experimental design was used and pots were arranged in a randomized complete block design with 10 replicates for each treatment.

Sugar beet seeds (6 seeds pot^{-1}) were sown on May 2, 2000. After sowing, the soil was irrigated with distilled water to keep 60-70% of the maximum water-holding

capacity (WHC), and then, one month after emergence, seedlings were thinned to one plant per pot and 0.19 g NH_4NO_3 kg^{-1} soil was added in liquid form. Yellow old leaves were separated carefully, oven-dried at 80 °C and were added to the dry weight of the second harvest. Plants were harvested 2 months (first harvest) and 6 months (second harvest) after sowing.

The average day temperature (Mannheimer hours) during the vegetation of this experiment from May 1st to October 29th 2000 is presented in Fig. 1.

Mannheimer hours = 1/4 (T_7^{00} + T_{14}^{00}+2 X T_{21}^{00})

T_7^{00}, T_{14}^{00} and T_{21}^{00} = Temperature degree celsius (°C) at 7, 14 and 21 hours, respectively.

3.1.2 Effects of water stress and substitution of K^+ by Na^+ related to the growth and water use efficiency of two sugar beet cultivars grown under natural conditions (Experiment 2)

This experiment was carried out in Ahr pots with 11.0 kg Kleinlinden soil for each pot under natural conditions. The soil was mixed with $MgCO_3$, $Ca(H_2PO_4)_2$ + $CaSO_4$ (superphosphate), NH_4NO_3 and H_3BO_3 at rates of 0.133, 1.91, 0.38 and 0.003 g/kg, respectively. Four treatments i. e. 5.0 g KCl; 3.75 g KCl + 0.98 g NaCl; 2.5 g KCl + 1.96 g NaCl; and 1.25 g KCl + 2.94 g NaCl were used. These treatments were equivalent to 0, 25, 50, and 75% of the molar standard concentration of K^+ being replaced by Na^+.

Sugar beet seeds (6 seeds pot^{-1}) were sown on April 28, 2001. After sowing, the soil was irrigated with distilled water to keep 60-70% of the maximum water-holding capacity (WHC). One month after emergence, the seedlings were thinned to one plant per pot and the application of two water treatments (40 and 70% WHC) was started. Where, 40 and 70% water-holding capacity were used until the first harvest, then all plants were grown uniformly under 70% WHC. A randomized complete block design was employed with factorial arrangement with 10 replicates for each treatment. Plants were harvested 3 months (first harvest) and 6 months (second harvest) after sowing. The average day temperature (Mannheimer hours) during the vegetation of this experiment from May 1st to October 29th 2001, is presented in Fig. 2.

3.1.3 Effect of drought and heat on the growth and sugar storage of two sugar beet cultivars grown in growth chambers (Experiment 3)

This experiment was carried out in small Mitscherlich pots filled with 6.0 kg Kleinlinden soil in two growth chambers under constant climatic conditions (day length: 16 h; relative humidity: 70%; and photosynthetic active radiation: 1300 µE m^{-2} s^{-1}). Halogen lamp "HRI-BT 400W/D" (Radium) and high pressure sodium lamps "SON-T-AHRO" (Philips) were used to raise temperature and light intensity. The soil was mixed with $MgCO_3$, $Ca(H_2PO_4)_2$ + $CaSO_4$ (superphosphate), NH_4NO_3, H_3BO_3 and KCl at rates of 0.133, 1.91, 0.38, 0.003 and 2.0 g kg^{-1} soil, respectively. A randomized complete block design was employed with factorial arrangement with 5 replicates for each treatment. At the beginning of May 2002 seeds were sown with 6 seeds per pot. After sowing, the soil was irrigated with distilled water to 60-70% of the maximum water-holding capacity. 30 days after emergence, seedlings were thinned to one plant per pot. Then two water treatments (40 and 70% WHC) and two treatments of temperature were used for each growth chamber as shown below:

Treatment	Temperature, day °C	Temperature, night °C	Water-holding capacity of the soil (WHC)
1	20	20	70%
2	35	25	70%
3	20	20	40%
4	35	25	40%

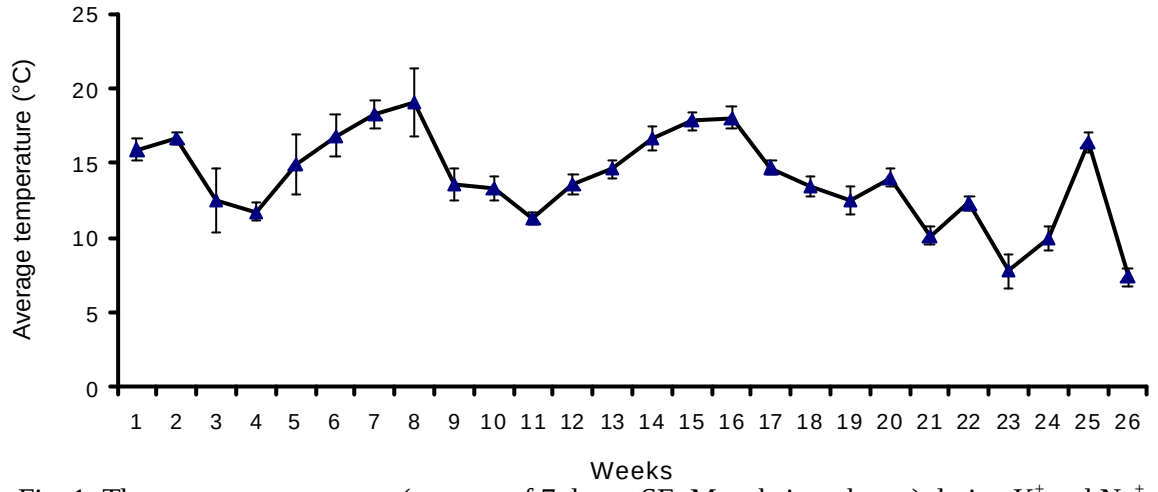

Fig. 1: The average temperature (average of 7 days ±SE, Mannheimer hours) during K^+ and Na^+ fertilization experiment in soil from May 1st to October 29th 2000 (Experiment 1)

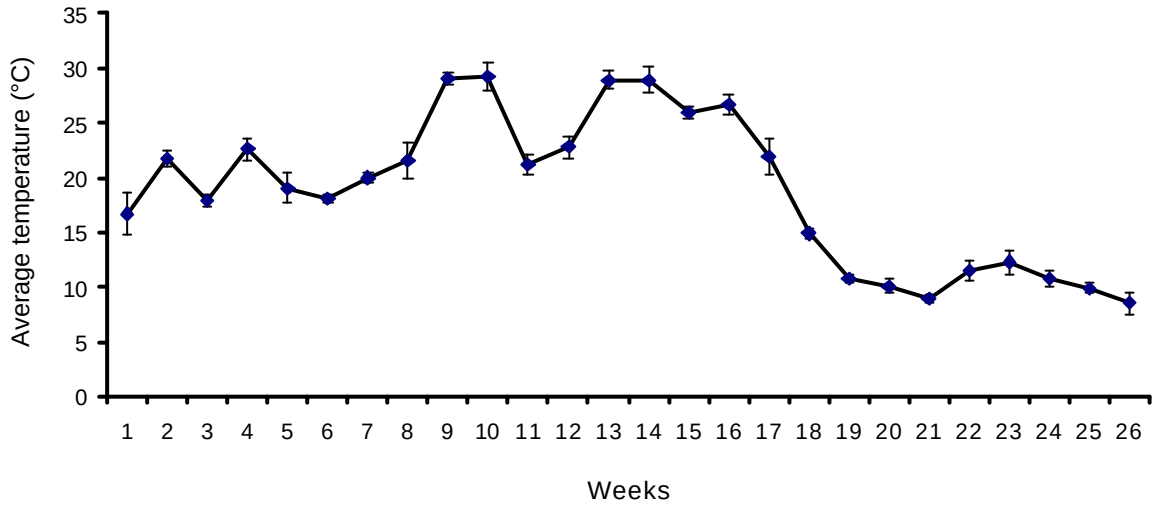

Fig. 2: The average temperature (average of 7 days ± SE, Mannheimer hours) during water stress and K^+/Na^+ substitution experiment in soil from May 1st to October 29th 2001(Experiment 2)

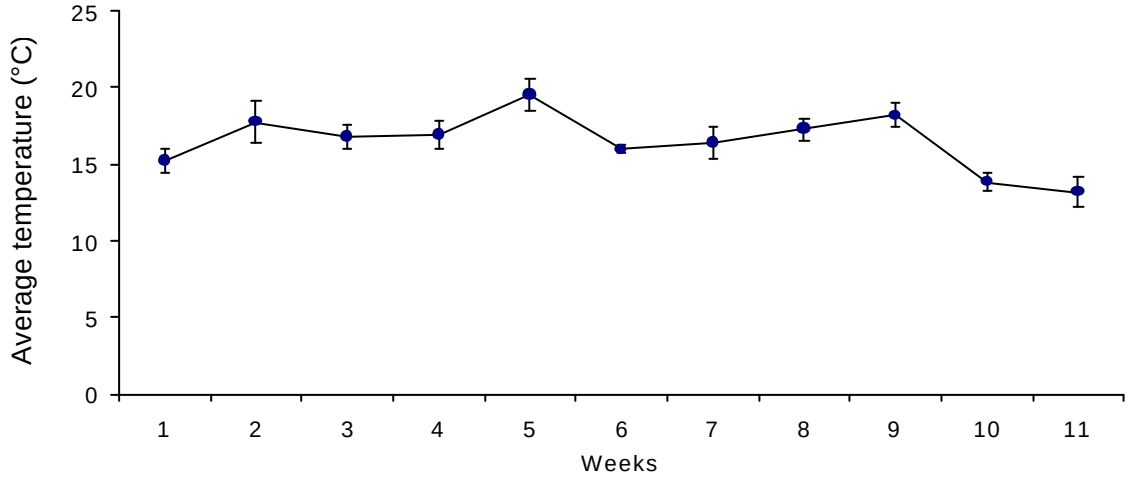

Fig. 3 The average of temperature (average of 7 days ± SE, Mannheimer hours) during K^+/Na^+ substitution experiment in nutrient solution from July 1st to Septemper 15th 2002 (Experiment 4)

3.2 Nutrient solution experiments

3.2.1 Effects of K^+ substitution by Na^+ on the growth of two sugar beet cultivars grown under natural conditions (Experiment 4)

All pots (Ahr pots and plastic containers) were washed in hot water and were sterilized with a Menno Florades solution (2%) in order to avoid an infection of fusarium.

Sugar beet seeds were germinated in sand under standardized environmental conditions. The seedlings were irrigated with 10 mM $CaSO_4$. The seedlings were allowed to grow to approximately 3 cm shoot length (1 week) and then were transferred to 1/4 strength nutrient solution in Ahr pots, which was replaced after 3 days by half and then after 3 days by full strength nutrient solution of the following composition:

4 mM KCl; 0.5 mM NH_4NO_3; 2.0 mM $Ca(NO_3)_2$; 0.5 mM $MgSO_4$; 0.3 mM $NH_4H_2PO_4$; 0.5 µM $MnSO_4$; 0.2 µM $CuSO_4$; 0.1 µM $ZnSO_4$; 10.0 µM H_3BO_3; 0.01µM $(NH_4)_6Mo_7O_{24}$ and 10.0 µM Fe-EDTA.

After 2 weeks of growth in the full nutrient solution, 9 treatments were established as shown below:

Treatment	mM KCl	mM NaCl
1	0.0	0.0
2	0.1	0.0
3	0.0	0.1
4	0.1	0.1
5 (control)	4.0	0.0
6	3.0	1.0
7	2.0	2.0
8	1.0	3.0
9	0.0	4.0

Furthermore, the sugar beet roots were dipped into 8 l of 0.3% (w/v) Benomyl solution for 5 min in order to avoid an infection of fusarium wilt (*Fusarium oxysporum* Schlechtend) before the change of the nutrient solution. Ahr pots with 9 l continuously aerated nutrient solution contained 1 plant and the solution was replaced twice a week. A randomized complete block design was employed with factorial arrangement with 6 replicates for each treatment. The water loss by transpiration was calculated for 24 h only before harvest. Plant were held in a hole of the cover with foam and the hole size was increased according to the size of plant each week. Plants were harvested 10 weeks after sowing. The average day temperature (Mannheimer hours) during this experiment from July 1st to September 15th 2002 is presented in Fig. 3.

3.2.2 Effect of Ca^{2+} deficiency on the growth of sugar beet plants grown in growth chamber (Experiment 5)

Sugar beet seeds (cv. Evita) were germinated in sand under standardized environmental conditions and irrigated with 10 mM $CaSO_4$ in a growth chamber (day length was 16 h at 40 W m^{-2} light intensity, 22 °C for day and 20 °C for night and relative humidity 70% and photosynthetic active radiation 1300 µE m^{-2} s^{-1}). The seedlings were allowed to grow approximately 3 cm (shoot length) in sand (1 week) and then were transferred to 1/4 strength nutrient solution, which was replaced after 3 days by a half strength and then after 3 days by a full strength nutrient solution described previously. After 2 weeks of growth in full nutrient solution, 5 treatments were used as shown below:

Treatments	mM $Ca(NO_3)_2$	mM $CaCl_2$	mM KNO_3	mM NH_4NO_3	mM KCl
2.0 mM $Ca(NO_3)_2$	2.0	0.0	0.0	0.5	4
2.0 mM $CaCl_2$	0.0	2.0	3	1	1
0.2 mM $CaCl_2$	0.0	0.2	3	1	1
0.1 mM $CaCl_2$	0.0	0.1	3	1	1
0.0 mM $CaCl_2$	0.0	0.0	3	1	1

The nutrient solution had the additional composition: 0.5 mM $MgSO_4$; 0.3 mM $NH_4H_2PO_4$; 0.5 µM $MnSO_4$; 0.2 µM $CuSO_4$; 0.1 µM $ZnSO_4$; 10.0 µM H_3BO_3; 0.01µM $(NH_4)_6Mo_7O_{24}$ and 10.0 µM Fe-EDTA.

The fungicide Benomyl 0.03% was used for each plant as described before. Each Ahr pot with 9 l continuously aerated nutrient solution contained 1 plant and the solution was replaced twice a week. Pots were arranged in a randomized complete block design with 4 replicates for each treatment. The cover with a hole in middle with foam was used as described previously. Plants were harvested 10 weeks after sowing.

3.3 Analyses

3.3.1 Water relations

3.3.1.1 Evapotranspiration (ET)

The evapotranspiration of each pot (plant + soil) was determined as the difference in weight of the pot after irrigation and its weight after 24 hours (before the next irrigation). The total water loss was calculated weekly from the same group of plants.

ET = the evapotranspiration of water from soil surface, plant leaves and through stomata's (transpiration) per ml H_2O.

3.3.1.2 Evapotranspiration rate (ER)

The evapotranspiration rate was estimated from the ratio between the amounts of water consumed per 1 hour relative to beet fresh weight per gram or to leaf area per m^2.

ER = ET / (LFW or LA)

Where, ET is the evapotranspiration of water, LFW is leaf fresh weight per gram and LA leaf area per m^2.

3.3.1.3 Evapotranspiration coefficient (EC)

Evapotranspiration coefficient was estimated from the ratio between the amounts of water consumed relative to beet dry weight per gram.

EC = ET/BDW

Where, ET is the evapotranspiration of water, BDW is beet dry weight per gram.

3.3.1.4 Water use efficiency (WUE)

Water use efficiency is generally used to express the ratio of dry matter production to amount of water consumed (evapotranspiration).

WUE = BDW/ET

Where, BDW is beet dry weight per gram and ET is the evapotranspiration of water from soil surface, plant leaves and through stomata's (transpiration) per ml H_2O

Also, T = the transpiration of water from plant leaves and through stomata's per ml H_2O, TR = transpiration rate, TC = transpiration coefficient and WUE = Water use efficiency for nutrition solution experiment.

3.3.2 Leaf area

Immediately after the harvest and separating the plant into leaves and beet, the leaf area was measured by drawing all leaves of each plant on squared papers. Then, each squared paper was cut around the drawing. After that the weight of papers was determined. The weight of 1 cm^2 of the squared paper was also determined. Then, leaf area was estimated from the ratio of weight of papers/weight of 1 cm^2.

3.3.3 Plant fresh and dry weight

After harvest, plants were washed with distilled water and separated into leaves and beet for fresh weight measurement. Before drying, the beets were cut with a knife in 1 cm small pieces in order to have a large surface for drying. After that the leaves and the sliced beet were oven-dried at 80 °C for 72 hours for dry weight measurement. The plant material was ground to pass a 1 mm sieve for further analysis.

3.3.4 Inorganic cations concentration

After grinding, the plant oven-dried material was used for the analysis of K^+, Na^+, Ca^{2+}, and Mg^{2+} concentrations. 500 mg of ground plant material was weighted into a porcelain crucible and ashed at 550 °C over-night in a forced oven. The cooled ash was carefully moistened with 2 ml of double-demineralized water and then dissolved in 5 ml of 5 M HNO_3. It was then heated prior to boiling followed by cooling and the ashed solution was filtered through "white-band 589" filter paper (Schleicher and Schüll Co., Dassel, Germany) to a 50 ml volumetric flask and filled up

to a volume of 50 ml with double-demineralized water. The cation concentrations in the extract were measured by using Atomic Absorption Spectrometry (Varian AA 220 FS).

3.3.5 Inorganic anions concentration

For the determination of inorganic anions, 200 mg of oven-dried plant material were weighted into 50 ml volumetric flask with 30 ml of double-demineralized water and then extracted on an end-over-end shaker kept in a water bath at 100 °C for 3 hours. After extraction, the volumetric flask was kept on ice and then filled up to the mark with double-demineralized water followed by filtration with (Faltenfilter $0790^{1/2}$) filter paper (Schleicher and Schüll Co., Dassel, Germany) and by SPE column (Octadecyl C_{18}). Water-soluble anions (Cl^-, NO_3^-, PO_4^{3-}, and SO_4^{2-}) were measured by means of ion chromatography (Metrohm Co., Germany).

3.3.6 α-Amino-N concentration

Analysis of α-amino-N concentration was done after extraction of 200 mg of ground dry material of leaves or beet with 20 ml phosphate buffer in 100 ml poly flask with an end-over-end shaker for 1 h and filtration with (Faltenfilter $595^{1/2}$ Schleicher and Schüll Co., Dassel, Germany). After filtration, 0.4 ml of the extract was mixed with 4 ml citrate buffer and 4 ml ninhydrin solution and was boiled in flask for 15 min in a water bath at 100 °C. After the flask was cooled down with water, the solution was added into a micro kuvette and α-amino-N concentration was determined by means of a spectrophotometer at a wave length of 570 nm. Glutamine standard was prepared in the same way and data were expressed in mmol α-amino-N/kg dry weight. Four replicates were analyzed for each treatment and the average was calculated.

The phosphate buffer had the following composition: 1.38 g NaH_2PO_4 + 1.78 g NaH_2PO_4 were added into a 1000 ml volumetric flask and volume was filled up to the mark with double-demineralized water to pH 7. The citrate buffer contained the following composition: 20 g $C_6H_8O_7$ was added into a 1000 ml volumetric flask with 200 ml 1 M NaOH solution and volume was filled up to the mark with double-demineralized water to pH 5.5. The ninhydrin solution contained 200 mg ninhydrin solved in 50 ml citrate buffer. After the solving of ninhydrin, 103.2 mg $SnCl_2$ were

added and this solution was stirred for 1h. For the glutamine standard 29.43 mg glutamine were solved in 100 ml phosphate buffer; this solution has a concentration of 2 mM glutamate).

3.3.7 Sugars concentration

For the analysis of sugars, 300 mg ground plant materials of beet of each treatment were weighted into 50 ml volumetric flask and 30 ml of double-demineralized water were added. The material was extracted on an end-over-end shaker at 60 °C for 30 min. After that, the volumetric flask was kept on ice and volume was made up to the mark with double-demineralized water followed by filtration with (blue-band 589) filter paper (Schleicher and Schüll Co., Dassel, Germany). After that the extract was diluted at a ratio 1:10. Sugars concentrations (Sucrose, glucose and fructose) were determined by using an enzymatic test kit (Boeringer Co. Germany). Four replicates were analyzed for each treatment and the average was calculated. The white sugar concentration of the beet was calculated with the "New Brunswick Formula" (Buchholz et. al. 1995).

With this formula the standardized molasses loss for a given quality of sugar beet was calculated:

$SMV = 0.12 \cdot w`_{K+Na} + 0.24 \cdot w`_{\alpha\text{-}N} + 0.48$

SMV standard molasses loss in % in beet

w` concentration of substance in mmol/100 g beet fresh weight

K + Na sum of potassium and sodium concentration

α-N α-amino nitrogen concentration

$BZG = w_z - SMV - 0.6$

BZG white sugar concentration in %

w_z sugar concentration of beet fresh weight

White sugar yield = (*BZG* · g beet fresh weight)/100

3.4 Statistical analysis

Data monitored in this study were subjected to an analysis of variance followed by a pair wise multiple comparison of treatment means by the least significant difference (LSD) test at 5% probability level, using Stat graphics, a computer software program (Statistical Graphics Corp., 1997).

4 Results

4.1 Soil culture experiments

4.1.1 Evaluation of the effects of K^+ and Na^+ fertilization on the growth of two sugar beet cultivars grown under natural conditions

In both cultivars (Evita and Sofie) the leaf fresh weight was significantly higher in the treatment with 5.0 g KCl pot^{-1} than 2.5 g KCl pot^{-1} (control) at the first and second harvest (Fig. 4). Leaf fresh weight was significantly lower at the high Na^+ treatment than at the high K^+ treatment. At the second harvest, leaf fresh weight was significantly increased in all treatments compared to 2.5 g KCl pot^{-1} for both cultivars. The highest leaf fresh weight was observed at 5.0 g KCl + 3.9 g NaCl pot^{-1} for both cultivars. The leaf fresh weight was lowered at the second harvest compared to the first harvest because the collected old yellowing leaves were not included in the leaf fresh weight determination. In contrast to the leaf yield, the beet yield was higher at the second harvest compared to the first harvest (Fig. 6).

Leaf dry weight decreased significantly at 2.0 g NaCl pot^{-1} compared to the control treatment (2.5 g KCl pot^{-1}) for the first harvest. Leaf dry weight was not significantly affected at the higher level of NaCl application, and the two treatments of K^+ and Na^+ combination for both cultivars compared to 2.5 g KCl pot^{-1} at the first harvest, whereas this was not observed at the second harvest (Fig. 5). At the second harvest, leaf dry weight increased significantly in all treatments (except 2.0 g for cultivar Sofie) for both cultivars. The highest leaf dry weight was obtained at 5.0 g KCl + 3.9 g NaCl pot^{-1} for both cultivars. Application of Na^+ in equivalent amounts to 2.5 and 5.0 g KCl pot^{-1} (2.0 g NaCl pot^{-1} and 3.9 g NaCl pot^{-1}) significantly increased the leaf dry weight for cultivar Evita, but this was not observed for cultivar Sofie (Fig. 5). At the first harvest, both fresh and dry weights of beets were significantly increased in all treatments compared to 2.5 g KCl pot^{-1}. However, at the second harvest fresh and dry weights of beets were reduced significantly only at 2.0 g NaCl pot^{-1} for cultivar Evita. Beet yield (both fresh and dry weights) increased significantly in all treatments compared to 2.5 g KCl pot^{-1} for cultivar Sofie (Fig. 6 and 7). Application of NaCl at equivalent amounts to 2.5

and 5.0 g KCl pot^{-1} significantly increased the beet yield for cultivar Evita at the first harvest and for cultivar Sofie at the second harvest. A positive effect of NaCl fertilization on the beet dry weight was observed for both cultivars at the first harvest and only for cultivar Sofie at the second harvest. Beet dry weight was reduced at 2.0 g NaCl application for cultivar Evita at the second harvest (Fig. 7).

The K^+ and Na^+ fertilization had a significant effect on the cation concentrations of leaves (Table 2). Leaf K^+ concentrations were significantly increased by increasing KCl application. Fertilization with both NaCl treatments reduced the leaf K^+ concentrations. At 5.0 g KCl + 3.9 g NaCl treatment the K^+ concentrations of leaves were significantly increased compared to the 2.5 g KCl treatment for both cultivars (Table 2). In beets, the K^+ concentrations were significantly decreased at the lower NaCl application for two cultivars at first harvest. However, the concentrations of K^+ increased significantly at 5.0 g KCl + 3.9 g NaCl treatment for cultivar Sofie for both harvests (Table 3). It is worth mentioning that leaf and beet K^+ concentrations in all treatments were higher at the first harvest relative to the second harvest. Also, it was noticed that Na^+ increased the K^+ uptake of the sugar beet plants. Leaf Na^+ concentrations increased significantly in the two Na^+ treatments for both cultivars at both harvests, however Na^+ concentrations of beets increased significantly at two Na^+ treatments only at the fist harvest (Table 2 and 3). Furthermore, the Ca^{2+} and Mg^{2+} concentrations of leaves and beets were slightly affected by different K^+ and Na^+ treatments (Table 2 and 3). Leaf Cl^- concentrations were significantly increased at 5.0 g KCl and two levels of K^+ and Na^+ combinations for both cultivars at the first harvest, and in all treatments of K^+ and Na^+ fertilization at the second harvest compared to the 2.5 g KCl treatment. Moreover, the highest Cl^- concentrations of leaves and beets were obtained at 5.0 g KCl + 3.9 g NaCl treatment for two cultivars for both harvests. On the other hand, NO_3^-, SO_4^{2-} and PO_4^{3-} concentrations of leaves and beets were decreased by increasing K^+ and Na^+ combinations (Table 4 and 5).

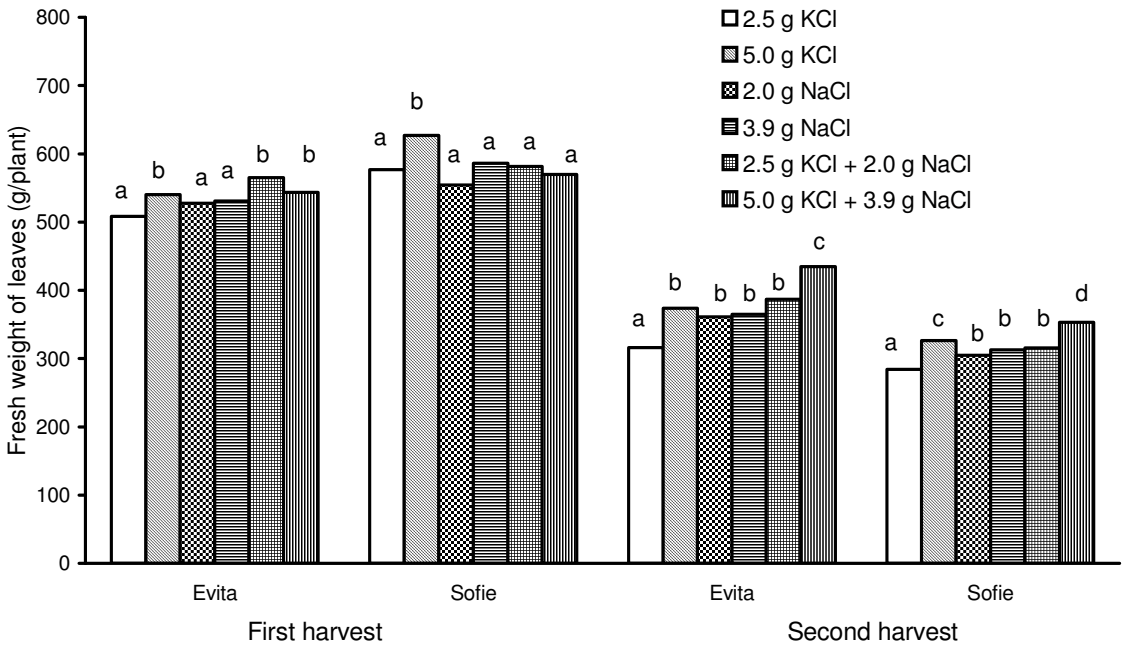

Fig. 4: Effect of K^+ and Na^+ fertilization on the fresh weight of leaves of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

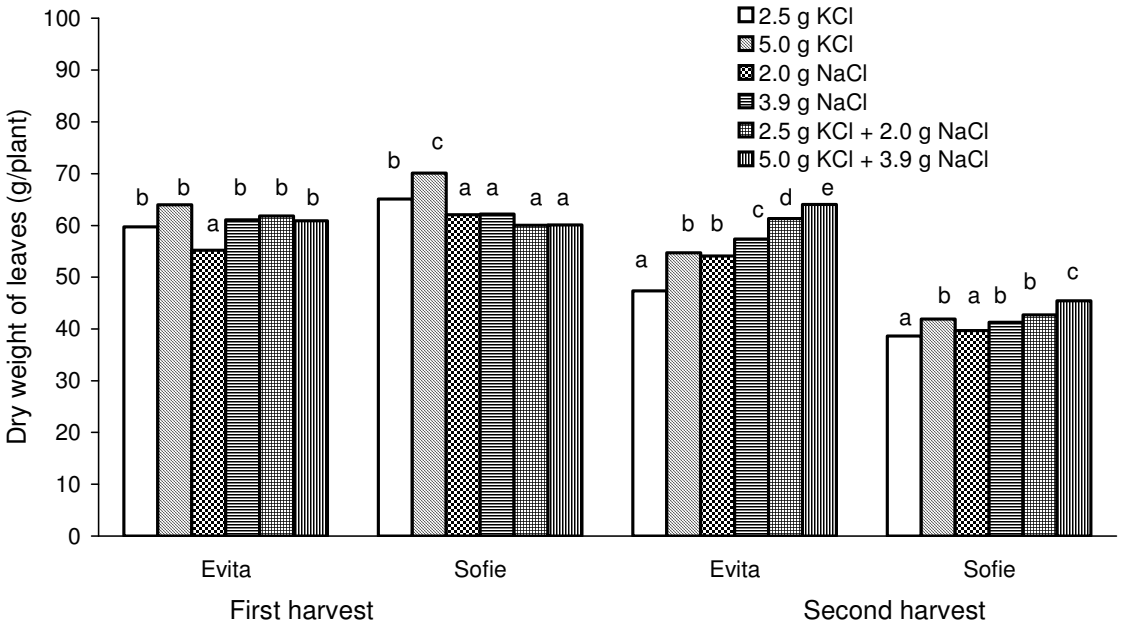

Fig. 5: Effect of K^+ and Na^+ fertilization on the dry weight of leaves of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

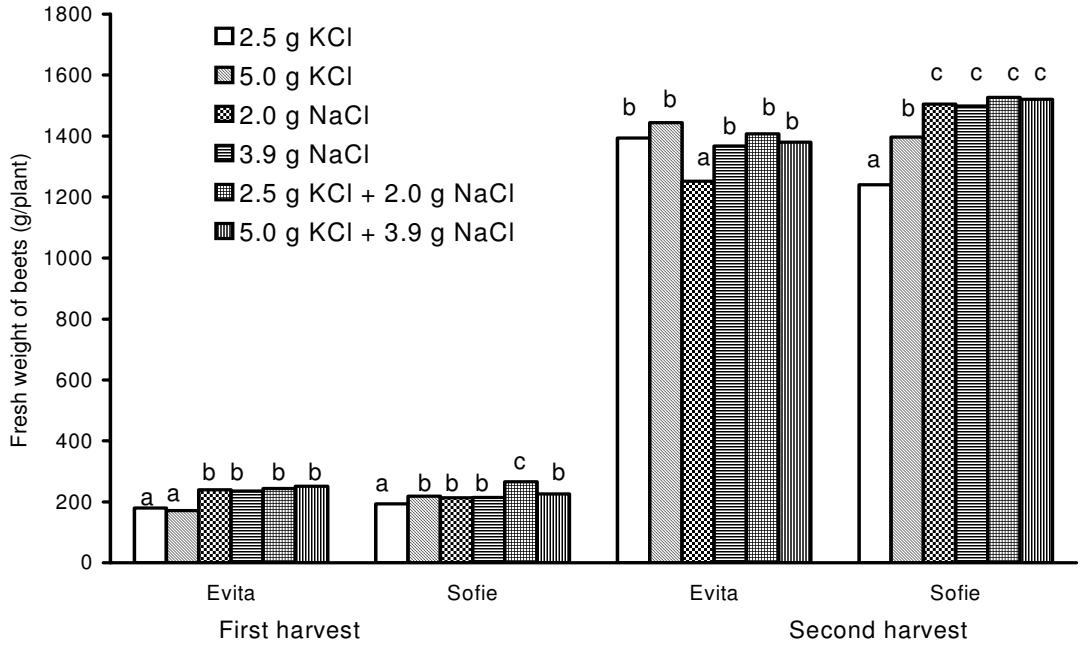

Fig. 6: Effect of K^+ and Na^+ fertilization on the fresh weight of beets of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

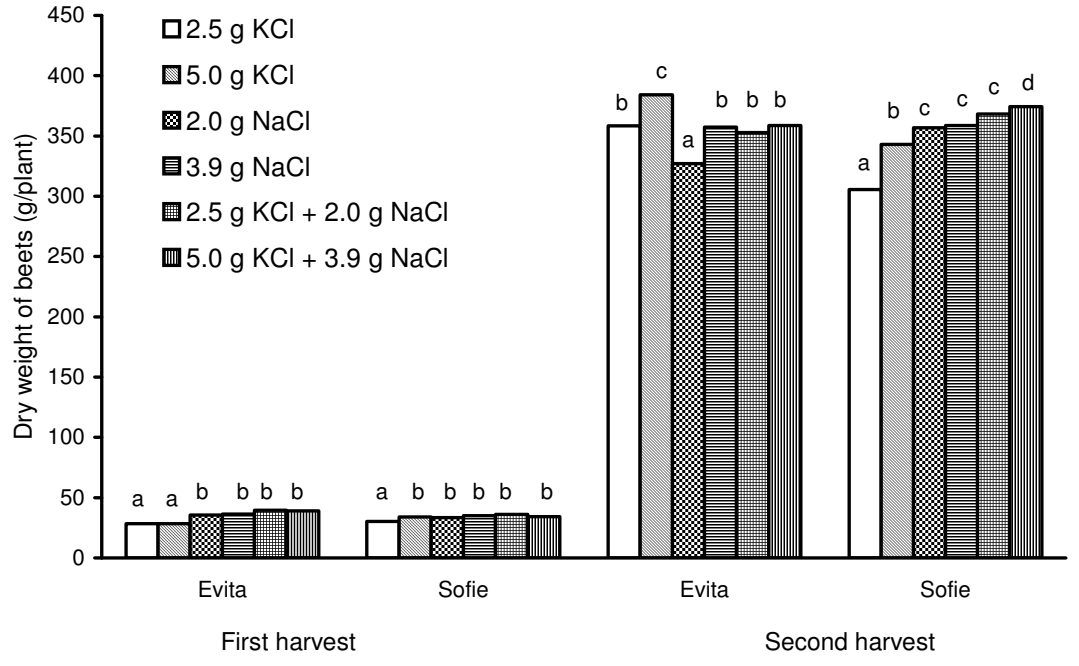

Fig. 7: Effect of K^+ and Na^+ fertilization on the dry weight of beets of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

Table 2: Effect of K^+ and Na^+ fertilization on the cation concentrations of leaves (mg/g DW) of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

Treatments g/pot	First harvest								Second harvest							
	Evita.				Sofie				Evita				Sofie			
	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}
2.5 KCl Control	24.2 b	4.20 a	14.8 b	16.8 b	22.0 b	4.1 a	17.0 b	15.8 b	18.8 a	2.1 a	18.1 a	11.8 a	18.6 a	2.2 a	18.8 a	11.7 a
5.0 KCl	30.1 c	4.10 a	11.5 a	15.4 b	27.3 c	3.8 a	16.3 b	14.2 b	23.6 b	1.8 a	18.2 a	11.5 a	19.4 b	2.0 a	18.4 a	11.3 a
2.0 NaCl	16.5 a	12.9 b	12.2 a	15.7 b	13.4 a	12.3 b	12.9 a	14.7 b	17.8 a	4.4 b	16.8 a	11.7 a	17.8 a	4.7 b	18.3 a	11.7 a
3.9 NaCl	22.5 b	11.5 b	11.2 a	13.8 a	18.9 b	11.8 b	12.6 a	12.5 a	17.2 a	4.6 b	19.3 a	13.9 b	14.8 a	4.9 b	18.3 a	12.4 ab
2.5 KCl + 2.0 NaCl	28.8 c	4.40 a	12.4 a	15.6 b	29.3 c	4.2 a	13.5 a	14.7 b	19.3 a	2.2 a	17.8 a	13.2 b	18.3 a	2.0 a	19.8 a	13.6 b
5.0 KCl + 3.9 NaCl	42.2 d	4.40 a	12.1 a	13.8 a	44.0 d	4.5 a	12.7 a	12.6 a	31.1 c	2.0 a	18.2 a	11.0 a	30.1 c	2.2 a	20.7 a	11.6 a
L.S.D 5%	2.84	1.14	1.66	1.62					4.11	0.57	3.66	1.34				

Critical values of cation concentrations according to Bergmann (1992):
35- 60 mg K^+/g DW
7-20 mg Ca^{2+}/g DW
3-7 mg Mg^{2+}/g DW

Table 3: Effect of K^+ and Na^+ fertilization on the cation concentrations of beets (mg/g DW) of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

Treatments g/pot	First harvest								Second harvest							
	Evita				Sofie				Evita				Sofie			
	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}
2.5 KCl Control	16.07 b	0.97 a	1.60 c	1.35 c	14.27 b	0.76 a	1.41 a	1.37 b	4.34 ab	0.22 a	1.12 a	0.94 b	4.19 a	0.22 b	1.26 b	0.98 b
5.0 KCl	15.83 b	0.56 a	1.39 bc	1.31 bc	16.11 c	0.65 a	1.34 a	1.35 b	4.38 ab	0.18 a	1.14 a	0.93 b	4.54 a	0.20 b	1.12 a	0.87 a
2.0 NaCl	12.78 a	2.07 b	1.29 b	1.23 bc	11.44 a	2.06 b	1.26 a	1.36 b	4.07 a	0.23 a	1.04 a	0.87 b	4.38 a	0.24 b	1.06 a	1.02 b
3.9 NaCl	14.99 b	1.95 b	1.26 ab	1.34 c	14.5 bc	2.13 b	1.38 a	1.21 a	4.23 ab	0.21 a	1.06 a	0.89 b	4.36 a	0.25 b	1.08 a	0.98 b
2.5 KCl + 2.0 NaCl	15.83 b	0.58 a	1.06 a	1.06 a	14.8 bc	0.62 a	1.20 a	1.38 b	4.30 ab	0.12 b	1.04 a	0.93 b	4.37 a	0.16 a	1.09 a	0.93 b
5.0 KCl + 3.9 NaCl	15.69 b	0.60 a	1.26 ab	1.21 b	19.56 d	0.77 a	1.31 a	1.39 b	4.69 b	0.13 b	1.23 a	0.74 a	5.18 b	0.13 a	1.14 a	0.81 a
L.S.D 5%	1.73	0.3	0.23	0.13					0.56	0.06	0.2	0.12				

Table 4: Effect of K^+ and Na^+ fertilization on the water-soluble anion concentrations of leaves (mg/g DW) of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

Treatments g/pot	First harvest								Second harvest							
	Evita				Sofie				Evita				Sofie			
	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
2.5 KCl Control	12.47 a	9.39 b	14.59 a	11.35 c	12.51 a	9.35 ab	14.93 b	11.54 c	12.66 a	3.68 c	13.98 b	10.89 b	12.0 a	3.28 b	14.22 b	11.47 b
5.0 KCl	15.95 b	8.42 ab	14.56 a	9.97 b	16.75 b	8.15 a	14.19 a	10.80 bc	17.22 b	2.35 ab	13.49 ab	9.89 b	19.82 b	2.39 a	13.03 a	10.31 b
2.0 NaCl	12.21 a	9.61 b	13.76 a	9.69 b	13.66 a	10.41 b	13.33 a	9.74 b	16.48 b	2.48 ab	13.12 ab	10.24 b	17.79 b	2.92 ab	14.01 a	10.39 b
3.9 NaCl	14.17 ab	9.26 b	12.93 a	8.41 a	14.58 ab	10.15 b	13.15 a	8.55 ab	18.6 b	2.13 a	12.20 a	9.01 ab	18.81 b	3.10 b	12.87 a	9.74 ab
2.5 KCl + 2.0 NaCl	16.39 b	7.58 a	13.24 a	8.31 a	16.26 b	8.64 a	12.96 a	8.3 a	21.84 c	2.30 ab	11.80 ab	8.82 ab	24.37 c	2.66 ab	12.08 a	8.70 a
5.0 KCl + 3.9 NaCl	23.31 c	7.58 a	13.43 a	8.54 ab	23.52 c	8.68 a	13.15 a	8.44 a	28.09 d	2.79 b	11.34 a	8.32 a	29.56 d	2.70 ab	11.68 a	8.39 a
L.S.D 5%	2.345	1.24	1.93	1.23					3.05	0.58	2.21	1.52				

Table 5: Effect of K^+ and Na^+ fertilization on the water-soluble anion concentrations of beets (mg/g DW)of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

Treatments g/pot	First harvest								Second harvest							
	Evita				Sofie				Evita				Sofie			
	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
2.5 KCl Control	2.16 b	3.37 c	5.85 a	2.03 a	2.0 ab	2.84 c	6.01 a	2.05 a	0.92 a	0.14 c	1.35 b	0.56 b	0.95 a	0.159 c	1.41 c	0.58 b
5.0 KCl	2.23 b	2.30 b	5.67 a	1.89 a	2.33 bc	2.48 bc	5.92 a	1.92 a	1.0 b	0.12 b	1.32 b	0.53 b	1.02 b	0.089 a	1.230 bc	0.54 ab
2.0 NaCl	1.86 a	2.39 b	6.07 a	1.95 a	1.82 a	2.35 b	6.13 a	1.98 a	0.88 a	0.11 b	1.16 b	0.56 b	0.92 a	0.142 bc	1.13 b	0.59 b
3.9 NaCl	2.12 ab	1.82 a	5.98 a	1.83 a	2.01 ab	1.86 a	5.98 a	1.89 a	0.93 a	0.12 b	0.83 b	0.53 b	0.98 ab	0.124 b	0.89 a	0.52 a
2.5 KCl + 2.0 NaCl	2.22 b	1.46 a	5.85 a	1.79 a	2.2 b	1.99 ab	5.92 a	1.83 a	1.03 bc	0.075 a	0.80 a	0.53 b	1.05 b	0.089 a	0.80 a	0.51 a
5.0 KCl + 3.9 NaCl	2.54 c	1.60 a	5.61 a	1.78 a	2.56 c	1.86 a	5.73 a	1.77 a	1.07 c	0.08 a	0.71 a	0.46 a	1.13 c	0.084 a	0.86 a	0.51 a
L.S.D 5%	0.26	0.44	0.70	0.31					0.063	0.027	0.21	0.069				

As compared to 2.5 g KCl, leaf α-amino-N concentrations increased significantly in all treatments (except 5.0 g KCl + 3.9 g NaCl) for two cultivars at both harvests (Fig. 8). At two treatments of NaCl application the leaf α-amino-N concentrations increased significantly for both harvests. The higher levels of α-amino-N concentrations of leaves and beets were observed at 3.9 g NaCl treatment for two cultivars at both harvests. Beet α-amino-N concentrations increased significantly in two treatments of NaCl application for both cultivars. However, the concentrations of α-amino-N of beets decreased significantly in two K^+ and Na^+ combinations (except for cultivar Evita at the first harvest) (Fig. 9). Conversely, lower level α-amino-N concentrations of beets were observed at K^+ and Na^+ combinations at the second harvest for both cultivars. Also, α-amino-N concentrations of beets were higher at the first harvest relative to at the second harvest (Fig. 8 and 9).

Sucrose concentrations (mg/g DW) of beets increased significantly in all treatments of K^+ and Na^+ fertilization (except 3.9 g NaCl) for two cultivars at the first harvest compared to 2.5 g KCl application (control). At the second harvest, however, the concentrations of sucrose decreased significantly at 3.9 g NaCl treatment for cultivar Evita, and at the two treatments of NaCl application for cultivar Sofie (Fig. 10). Sucrose concentrations (expressed as % FW) reduced significantly at lower Na^+ application for cultivar Evita, and at lower level of K^+ and Na^+ combinations for cultivar Sofie at the first harvest. Similarly, at the second harvest, sucrose concentrations decreased significantly at higher Na^+ application and at lower K^+ and Na^+ combinations for cultivar Evita. For cultivar Sofie the concentrations of sucrose decreased significantly at two treatments of NaCl application (Fig. 11). The sugar yield increased significantly in all treatments for both cultivars (except 5.0 g KCl application for cultivar Evita) at the first harvest (Fig. 12). At the second harvest, sugar yield increased significantly at 5.0 g KCl treatment, but it was significantly reduced at two NaCl applications for cultivar Evita. Sugar yield increased significantly in all treatments for cultivar Sofie (Fig. 13). The same trend was obtained for white sugar yield (Fig. 12 and 13).

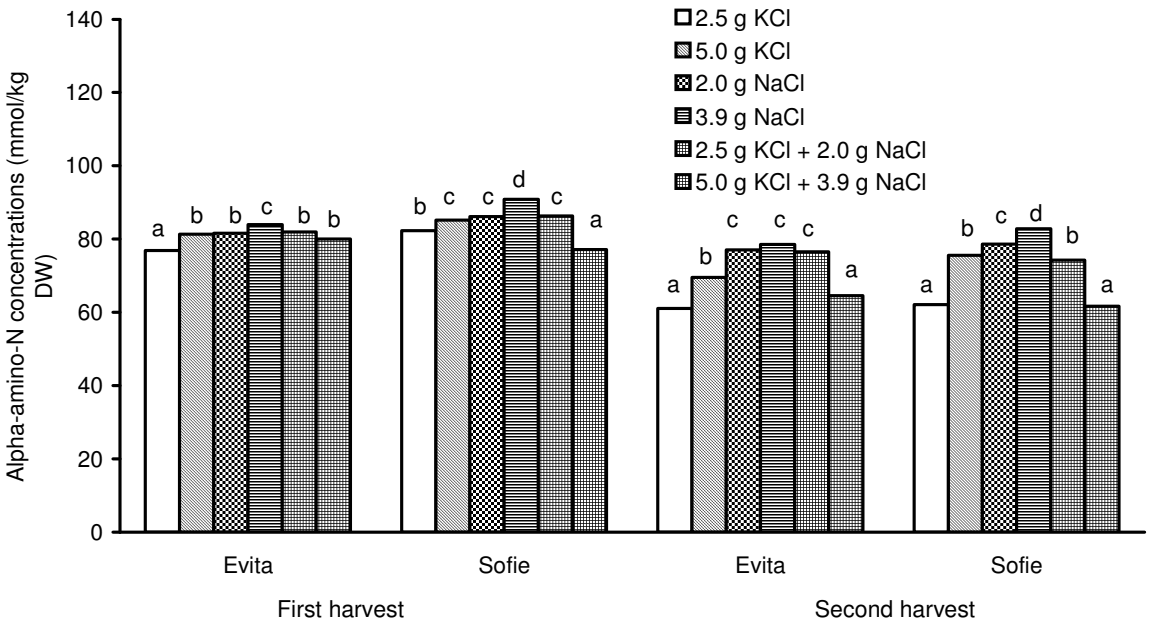

Fig. 8: Effect of K^+ and Na^+ fertilization on the alpha-amino-N concentrations of leaves of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

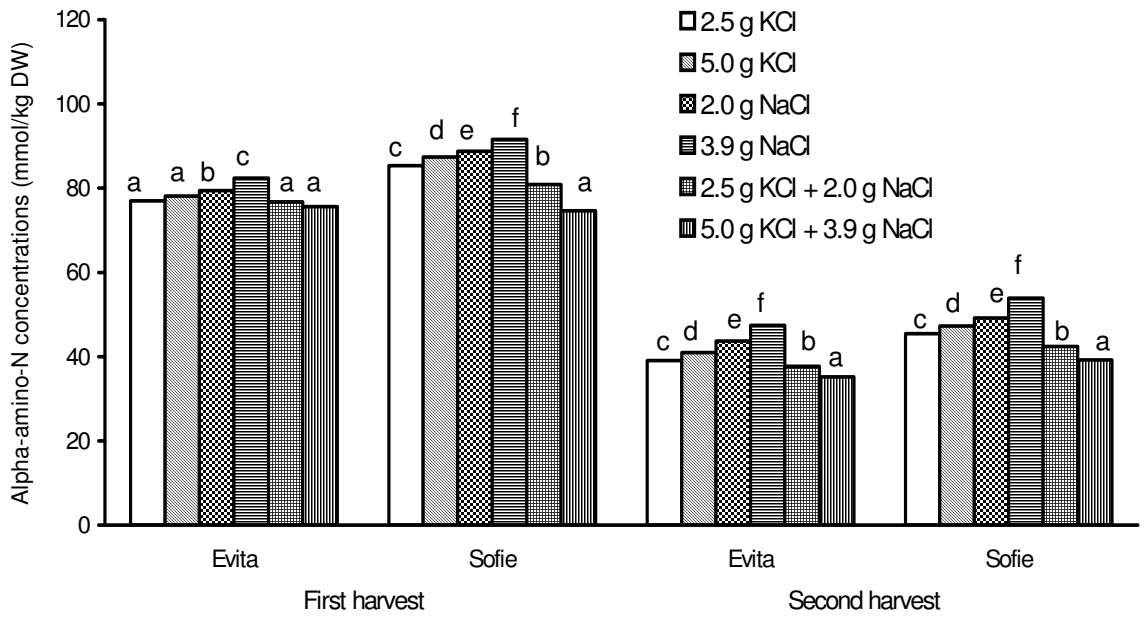

Fig. 9: Effect of K^+ and Na^+ fertilization on the alpha-amino-N concentrations of beets of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months,

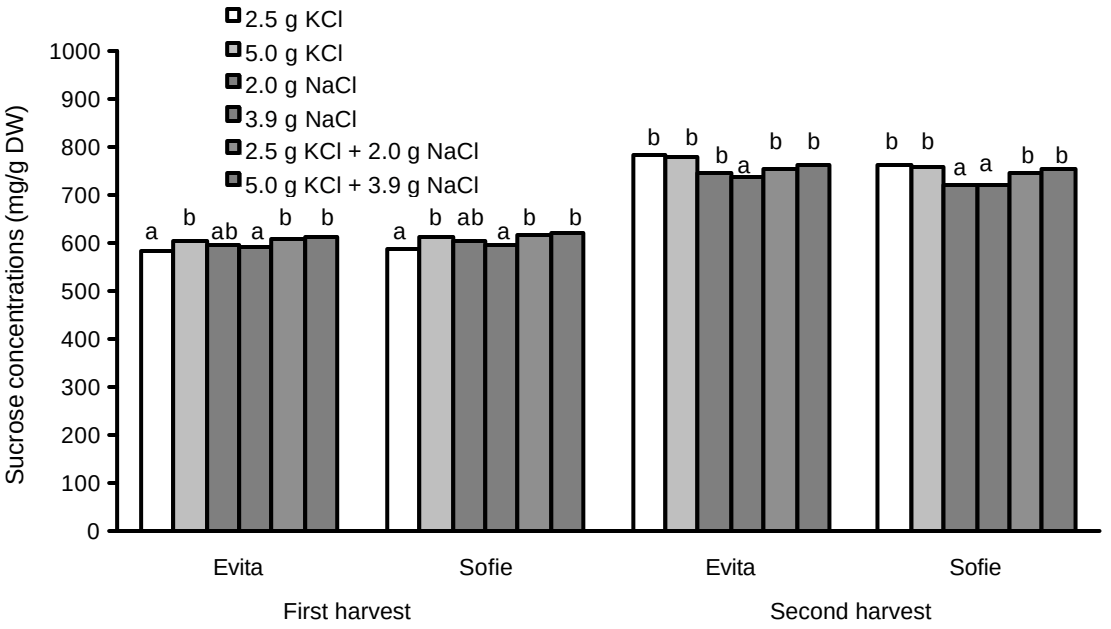

Fig. 10: Effect of K^+ and Na^+ fertilization on the sucrose concentrations of beets of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

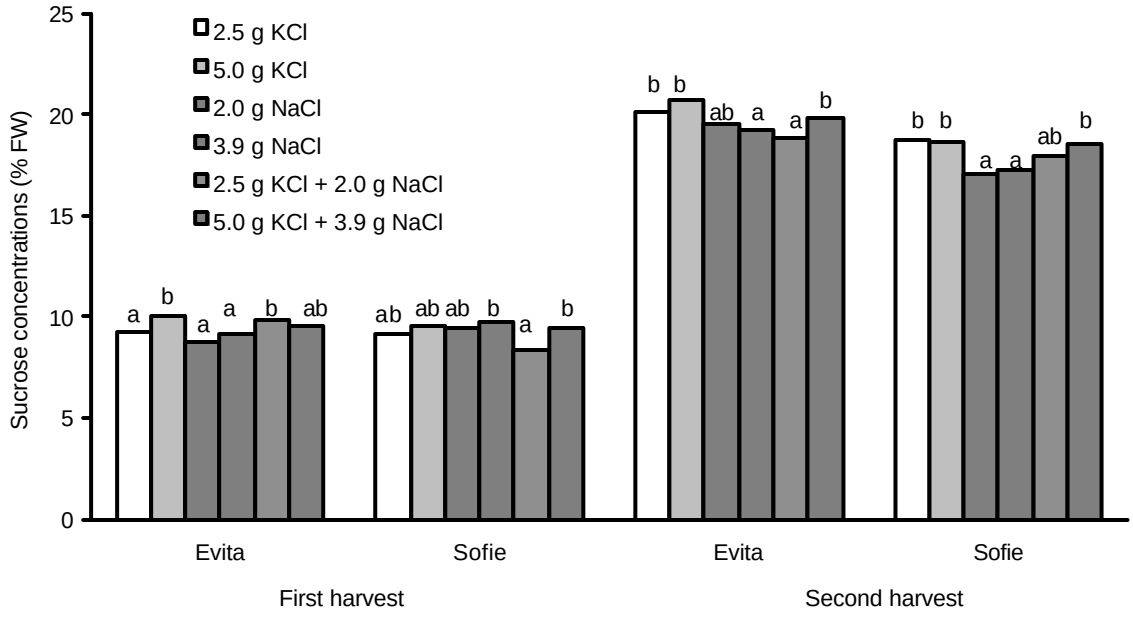

Fig. 11: Effect of K^+ and Na^+ fertilization on the sucrose concentrations of beets of two sugar beet cultivars grown in soil under natural conditions for 2 and 6 months, respectively

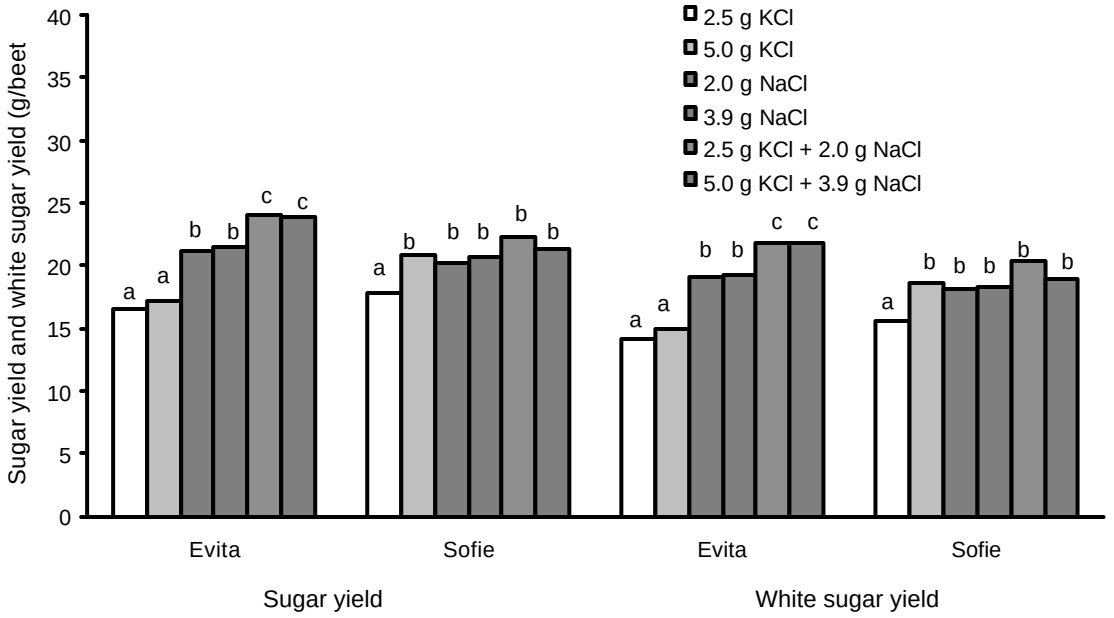

Fig. 12: Effect of K^+ and Na^+ fertilization on sugar yield and white sugar yield of beets of two sugar beet cultivars grown in soil under natural conditions for 2 months

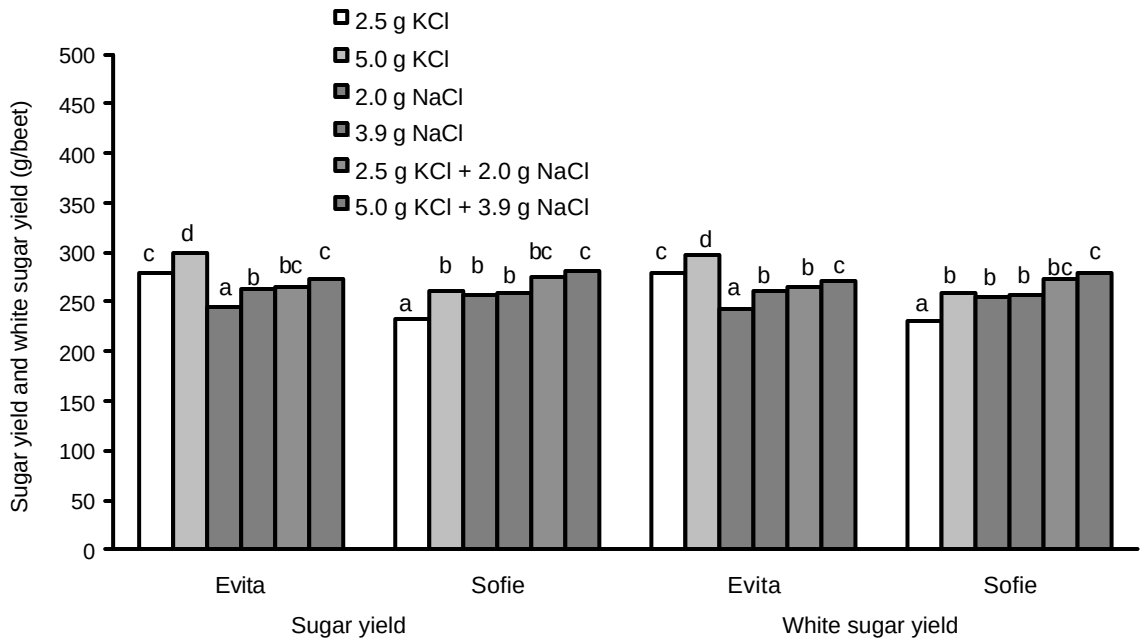

Fig. 13: Effect of K^+ and Na^+ fertilization on the sugar yield and white sugar yield of beet of two sugar beet cultivars grown in soil under natural conditions for 6 months

Table 6, 7 and 8 show the main results of the analysis of variance of the K^+ and Na^+ fertilization experiment. A significant effect of K^+ and Na^+ fertilization was observed on leaf and beet fresh and dry weights for both harvests. The effect of genotype was significantly different on leaf fresh and dry weights for both harvests (Table 6). Also, a significant effect of K^+ and Na^+ fertilization was observed on all cations, sugar concentrations, and sugar and white sugar yields for both harvests (Table 7 and 8).

Table 6: Analysis of variance of K^+ and Na^+ fertilization on plant growth of two sugar beet genotypes grown in soil for 2 and 6 months, respectively

Source	First harvest							
	Leaf fresh weight		Leaf dry weight		Beet fresh weight		Beet dry weight	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Genotype	31816.4	33.85**	114.5	8.2*	45.4	0.12 NS	7.29	0.84 NS
Treatment	2821.5	3.0*	79.8	5.74**	6641.7	18.1**	109.9	12.7 NS
Error	940.0		13.9		366.67		8.66	
	Second harvest							
Genotype	49432.9	261.7**	3173.2	508.7**	82140	12.04*	436.4	1.3 NS
Treatment	9348.3	49.5**	170.0	27.3**	30120	4.42*	1870.9	5.4**
Error	188.9		6.2		6821.5		349.9	

* Significant, ** highly significant and NS not significant.

Table 7: Analysis of variance of K^+ and Na^+ fertilization on cation concentrations of two sugar beet genotypes grown in soil for 2 and 6 months, respectively

Source	Leaves				Beets			
	First harvest							
	K^+		Na^+		K^+		Na^+	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Genotype	36.8	6.5*	0.23	0.31^{NS}	0.09	0.04 NS	0.06	0.98^{NS}
Treatment	933.3	164.2**	167.8	223.5**	32.5	12.1**	5.61	97.27**
Error	5.7		0.75		2.7		0.06	
	Ca^{2+}		Mg^{2+}		Ca^{2+}		Mg^{2+}	
Genotype	49.2	23.2**	18.7	12.7**	0.001	0.03^{NS}	0.12	7.9*
Treatment	21.7	10.2**	15.6	10.6**	0.15	4.5*	0.02	1.3^{NS}
Error	2.1		1.5		0.03		0.02	
	Second harvest							
	K^+		Na^+		K^+		Na^+	
Genotype	31.1	3.1^{NS}	0.42	2.2^{NS}	0.83	4.6*	0.006	3.2^{NS}
Treatment	272.7	27.0**	17.8	93.3**	0.89	5.0**	0.02	11.2**
Error	10.1		0.2	0.57	0.18		0.002	
	Ca^{2+}		Mg^{2+}		Ca^{2+}		Mg^{2+}	
Genotype	13.7	1.74^{NS}	0.3	0.39^{NS}	0.01	0.3^{NS}	0.03	3.4^{NS}
Treatment	4.0	0.51^{NS}	8.7	7.6**	0.04	1.5^{NS}	0.04	4.5*
Error	7.9		1.1		0.03		0.01	

Table 8: Analysis of variance of K^+ and Na^+ fertilization on the sugar concentrations, sugar yield and white sugar yield of two sugar beet genotypes grown in soil for 2 and 6 months, respectively

Source	First harvest					
	Sucrose		Glucose		Fructose	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Genotype	543.0	2.0 ^{NS}	1.97	0.79 ^{NS}	0.37	0.53 ^{NS}
Treatment	1429.3	5.2**	93.87	26.73**	48.15	19.03**
Error	273.5		1.12		2.32	
	Sucrose % FW		Sugar yield		White sugar yield	
Genotype	0.32	0.56 ^{NS}	0.8	0.2 ^{NS}	0.56	0.16 ^{NS}
Treatment	0.7	1.23 ^{NS}	50.6	13.8**	51.9	15.2**
Error	0.6		3.7		3.4	
	Second harvest					
	Sucrose		Glucose		Fructose	
Genotype	3768.2	4.21*	4.73	1.32 ^{NS}	1.82	1.2 ^{NS}
Treatment	3262.8	3.64*	118.01	32.99**	63.7	42.15**
Error	895.55		3.58		1.51	
	Sucrose % FW		Sugar yield		White sugar yield	
Genotype	1455.3	4.36*	42.185	34.63**	1486.03	4.42*
Treatment	1386.9	4.15*	3.91	3.21*	1394.73	4.15*
Error	333.91		1.22		336.24	

4.1.2 Effects of water stress and substitution of K^+ by Na^+ related to the growth and water use efficiency of two sugar beet cultivars grown under natural conditions

In this experiment, 40 and 70% water-holding capacity (WHC) were used until the first harvest, and then all plants were grown uniformly under 70% WHC.

Water stress (40% WHC) reduced the leaf and beet fresh weight of both cultivars compared to the non-stress (70% WHC) conditions. At the first harvest, leaf fresh weight increased significantly in all treatments of K^+ substitution by Na^+ compared to 100% KCl application at 70% WHC. Under water stress leaf fresh weight was significantly increased at 50 and 75% K^+ substitution only in cultivar Evita (Fig. 14). At the second harvest, leaf fresh weight was hardly affected by substitution of K^+ by Na^+ for both cultivars (Fig. 15). Water stress and K^+ substitution by Na^+ had hardly any effect on the dry weight of leaves. Leaf dry weight was not significantly affected in all treatments for both cultivars at both harvests under two water treatments (Fig. 16 and 17).

At the first harvest, beet fresh weight was significantly increased by increasing K^+ substitution at 70 % WHC for two cultivars. Under water stress, beet fresh weight was significantly higher at 25 and 50% K^+ substitution for cultivar Evita and only with 50% K^+ substitution for cultivar Sofie (Fig. 18). At the second harvest, fresh weight of beets increased significantly in all treatments of K^+ substitution by Na^+ for both cultivars (except 75% K^+ substitution for cultivar Sofie) at 70% WHC. At 40-70% WHC, beet fresh weight was reduced significantly at 50 and 75% K^+ substitution for both cultivars (Fig. 19). Dry weight of beets was significantly affected by water stress and K^+/Na^+ substitution (Fig. 20). At the first harvest, beet dry weight increased significantly in all treatments of K^+ substitution by Na^+ for both cultivars (except at 25% K^+ substitution for cultivar Evita) at 70% WHC. Under water stress, beet dry weight increased significantly at 25 and 50% Na^+ substitution for cultivar Evita, but it decreased significantly at 75% Na^+ substitution for cultivar Sofie (Fig. 20). At the second harvest, dry weights of beets were significantly higher at 25% K^+ substitution for both cultivars at 70% WHC. However with 75% K^+ substitution the beet dry weight was significantly reduced only for cultivar Evita at 40-70%

WHC (Fig. 21). It is worth mentioning that water stress reduced sugar beet growth by reducing the leaf and beet fresh weight. At the first harvest, the mean reductions were 30-38% for leaves and 25-37% for beets fresh weight. The mean reductions were 16-27% for leaves and 12-36% for beets dry weight. At the second harvest, the mean reductions were 0.3-6% for leaves and 16-30% for beets fresh weight, while the reduction in dry weight was 0.4-5% for leaves and 23-32% for beet, respectively (Table 9).

At 70% WHC, the evapotranspiration (ET) increased significantly by the increase of K^+ substitution by Na^+ for the cultivar Sofie for both harvests. Under water stress, the ET was significantly reduced in all treatments of K^+ substitution by Na^+ compared to 100% KCl for both cultivars at the first harvest. In only 50% of K^+ substitution by Na^+, ET was significantly reduced for both cultivars at the second harvest (Fig. 22 and 23). However, evapotranspiration rate (ER) was significantly decreased at 50 and 75% K^+ substitution for cultivar Evita under 40% WHC and at 25 and 50% K^+ substitution for both cultivars under water stress (Fig. 24). At the first harvest, evapotranspiration coefficient (EC) of beets was significantly reduced at 50 and 75% K^+ substitution by Na^+ for both cultivars at 70% WHC (Fig. 25). Under water stress, EC was significantly lowered at 25 and 50% K^+ substitution only for cultivar Evita. At the second harvest, EC increased significantly only at 75% K^+ substitution for both cultivars (Fig. 26). At the first harvest, water use efficiency (WUE) of beets was significantly increased at 50 and 75% K^+ substitution at 70% WHC for cultivar Evita. Under water stress conditions, WUE increased significantly at 25 and 50% K^+ substitution for both cultivars (Fig. 27). At the second harvest, WUE increased significantly at 25 and 75% K^+ substitution for both cultivars at 70% WHC for cultivar Evita at 40-70% WHC (Fig. 28). It is evident that at 70% WHC, ET was found to be higher in Na^+ -treated plants than K^+-treated plants. However, this was not observed under water stress condition.

Leaf area increased significantly with increasing K^+ substitution. The highest leaf area was observed at 50% K^+ substitution for two cultivars under both water treatments (Fig. 29).

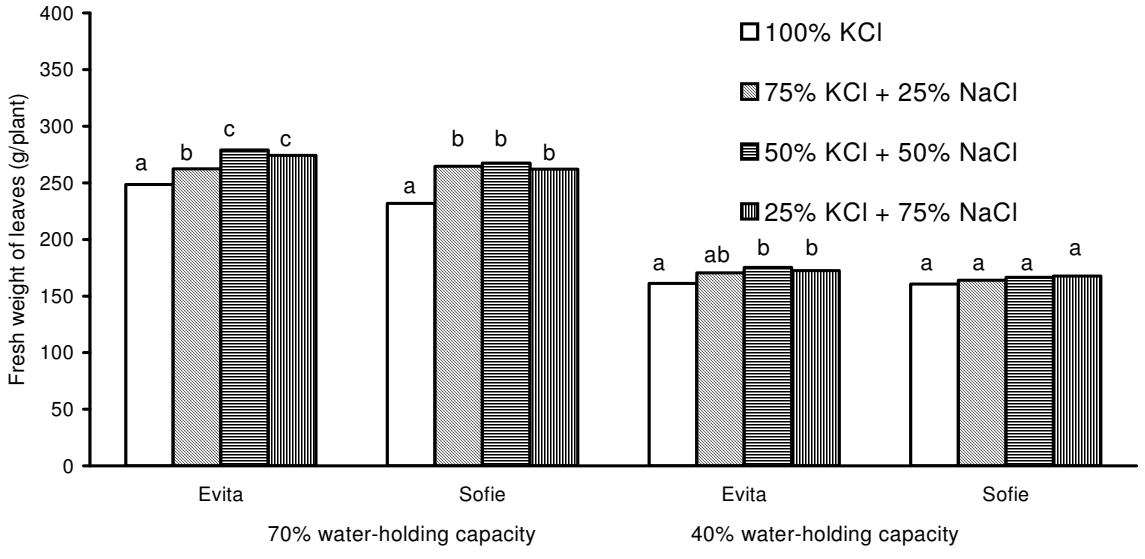

Fig. 14: Effect of water stress and K^+ substitution by Na^+ on the fresh weight of leaves of two sugar beet cultivars grown in soil under natural conditions for 3 months

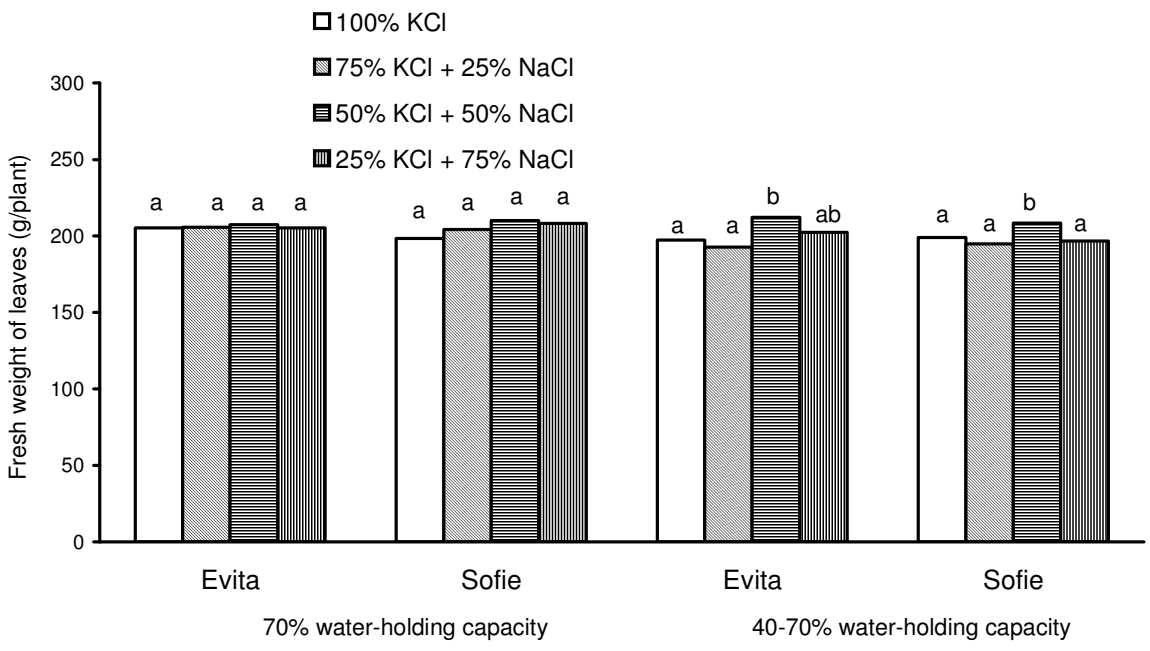

Fig. 15: Effect of water stress and K^+ substitution by Na^+ on the fresh weight of leaves of two sugar beet cultivars grown in soil under natural conditions for 6 months

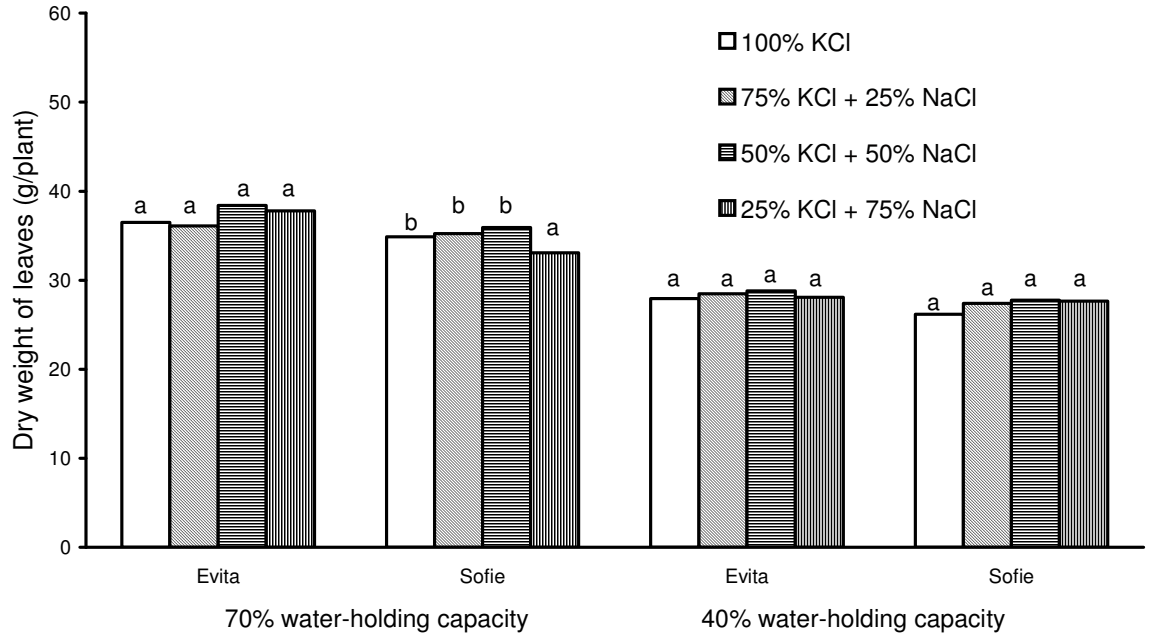

Fig. 16: Effect of water stress and K^+ substitution by Na^+ on the dry weight of leaves of two sugar beet cultivars grown in soil under natural conditions for 3 months

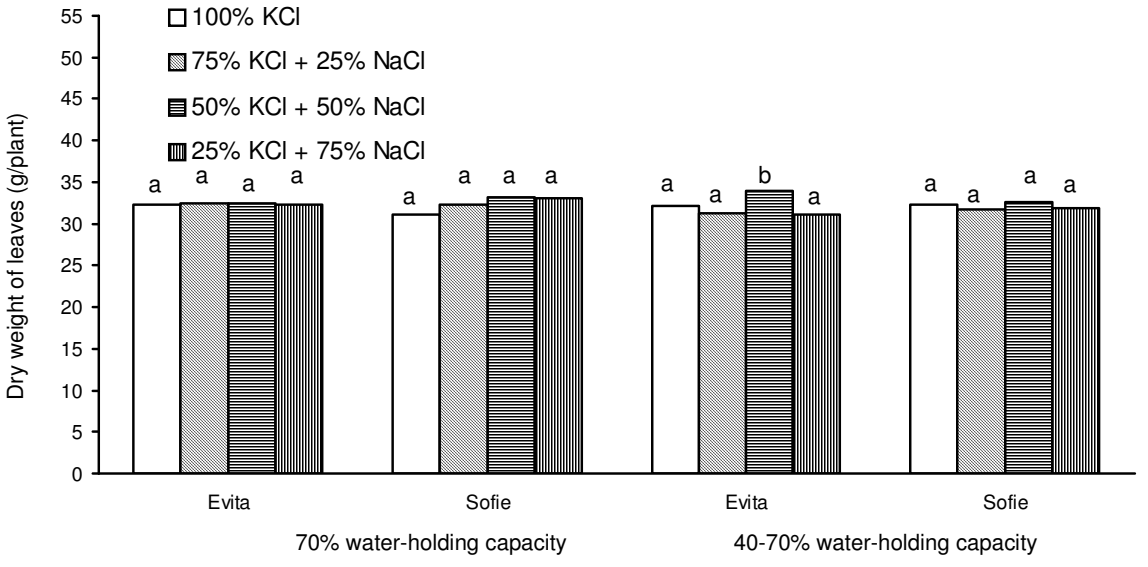

Fig. 17: Effect of water stress and K^+ substitution by Na^+ on the dry weight of leaves of two sugar beet cultivars grown in soil under natural conditions for 6 months

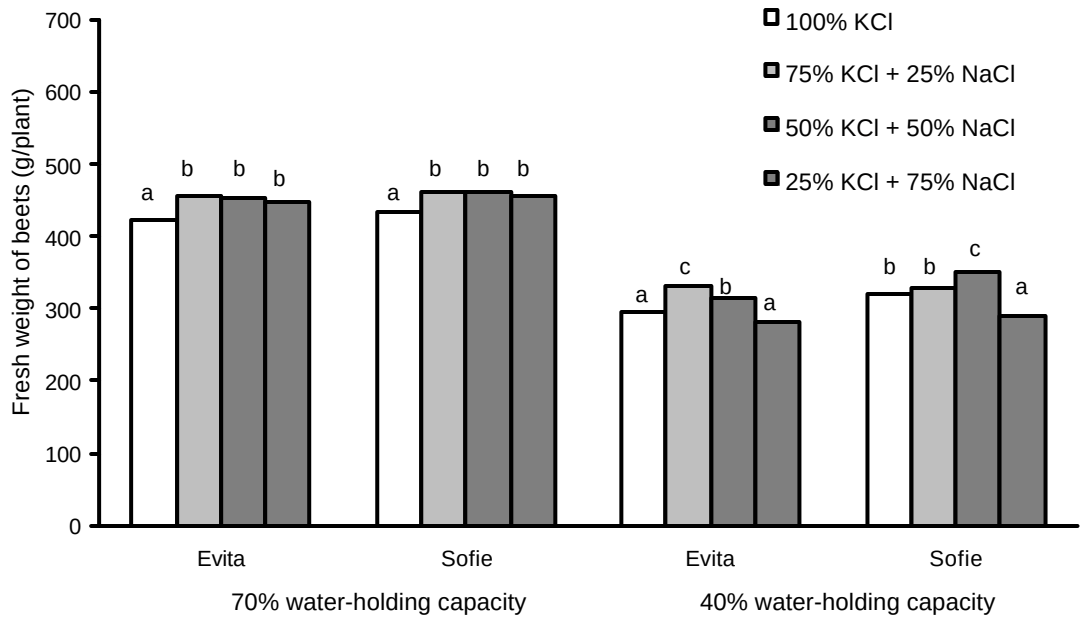

Fig. 18: Effect of water stress and K^+ substitution by Na^+ on the fresh weight of beets of two sugar beet cultivars grown in soil under natural conditions for 3 months

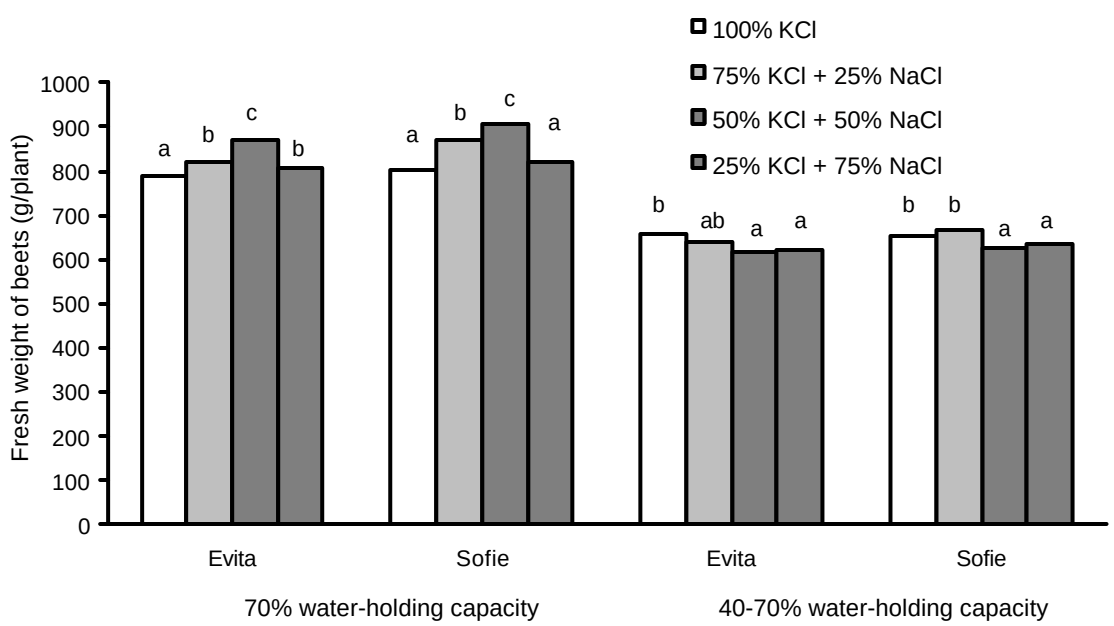

Fig. 19: Effect of water stress and K^+ substitution by Na^+ on the fresh weight of beets of two sugar beet cultivars grown in soil under natural conditions for 6 months

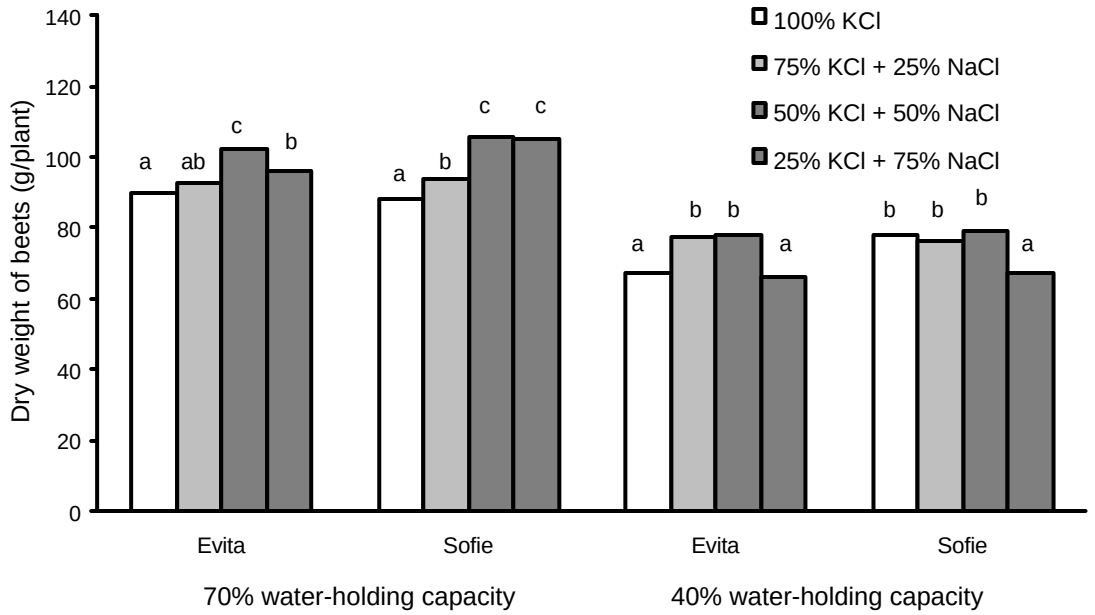

Fig. 20: Effect of water stress and K^+ substitution by Na^+ on the dry weight of beets of two sugar beet cultivars grown in soil under natural conditions for 3 months

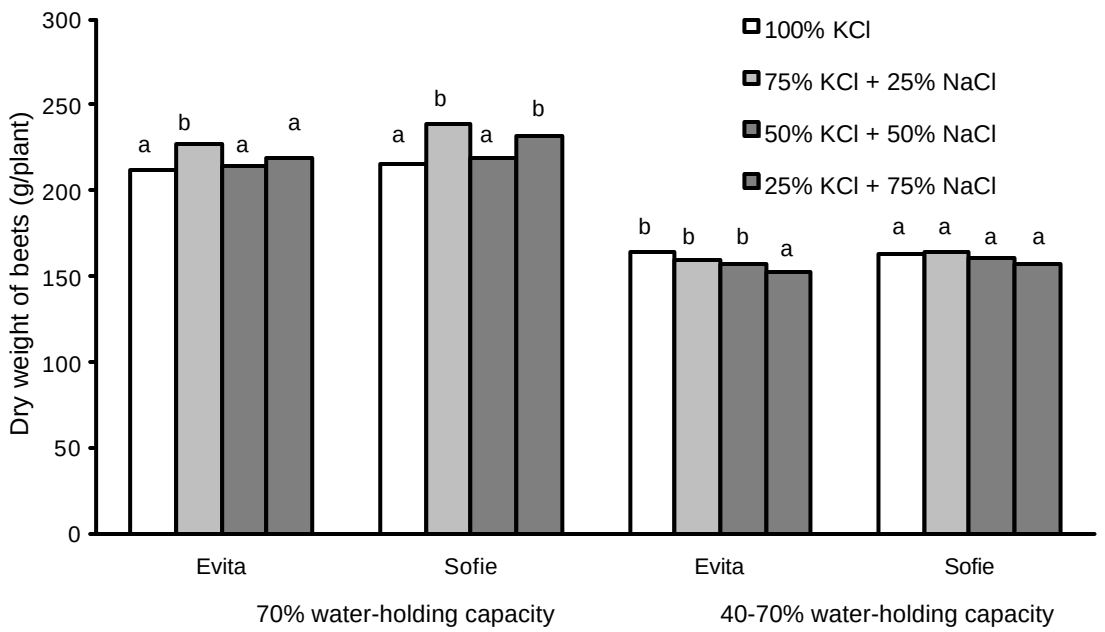

Fig. 21: Effect of water stress and K^+ substitution by Na^+ on the dry weight of beets of two sugar beet cultivars grown in soil under natural conditions for 6 months

Table 9: Effect of water stress on the plant growth reduction of two sugar beet cultivars grown in soil under natural conditions for 3 and 6 months, respectively

Treatments	First harvest								Second harvest							
	Leaves				Beets				Leaves				Beets			
	% Fresh weight		% Dry weight		% Fresh weight		% Dry weight		% Fresh weight		% Dry weight		% Fresh weight		% Dry weight	
	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie
100% KCl Control	35.17 a	30.72 a	23.44 b	24.94 b	30.05 b	25.94 a	25.09 b	11.99 a	3.87 b	0.26 a	0.37 a	3.86 b	16.75 a	18.62 a	22.78 a	24.68 a
75% KCl + 25% Nacl	35.03 a	38.03 b	21.01 a	22.25 b	27.18 a	28.59 b	16.65 a	18.31 b	6.24 c	4.62 b	3.55 b	1.92 a	22.33 b	23.10 b	29.70 c	31.00 b
50% KCl + 50% NaCl	37.14 b	37.75 b	24.50 b	22.66 b	30.55 b	28.46 b	23.55 b	24.99 c	2.34 a	0.80 a	4.70 b	1.77 a	28.39 c	30.14 c	26.88 b	26.59 b
25% KCl + 75% NaCl	37.03 a	36.05 b	25.66 b	16.44 a	36.67 c	36.65 c	31.28 c	35.70 d	1.44 a	5.61 b	3.69 b	3.51 b	23.59 b	23.78 b	30.47 c	32.29 b
L.S.D 5%	1.86	2.13	2.12	2.34	2.32	2.22	2.17	4.46	1.46	1.66	1.22	1.42	2.43	2.41	2.46	2.16

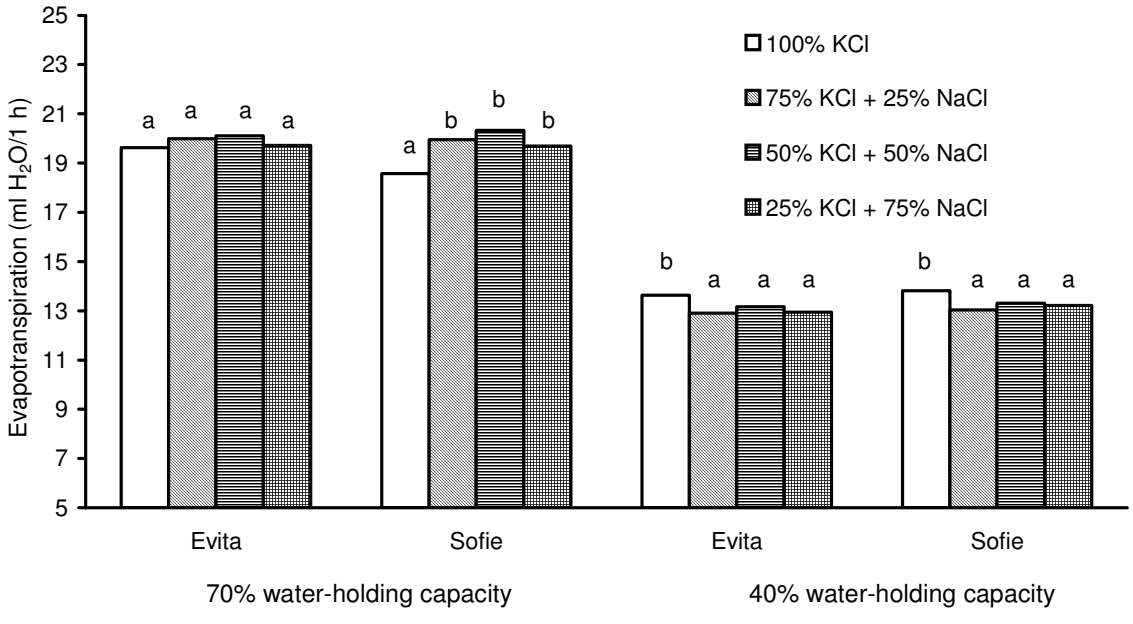

Fig. 22: Effect of water stress and K^+ substitution by Na^+ on the evapotranspiration of two sugar beet cultivars grown in soil under natural conditions for 3 months

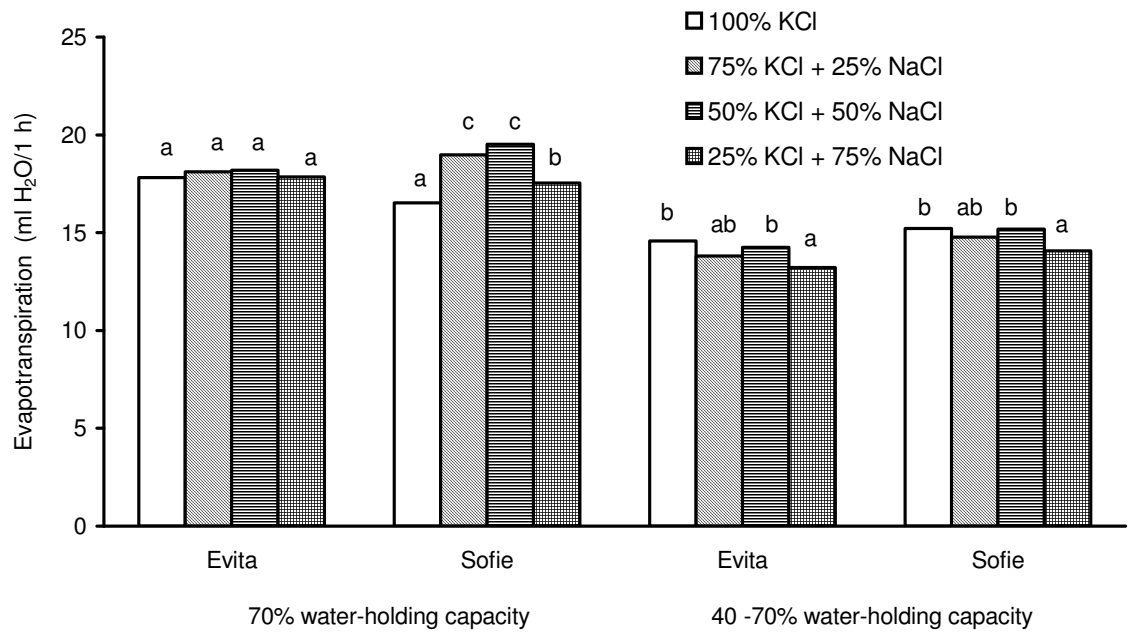

Fig. 23: Effect of water stress and K^+ substitution by Na^+ on the evapotranspiration of two sugar beet cultivars grown in soil under natural conditions for 6 months

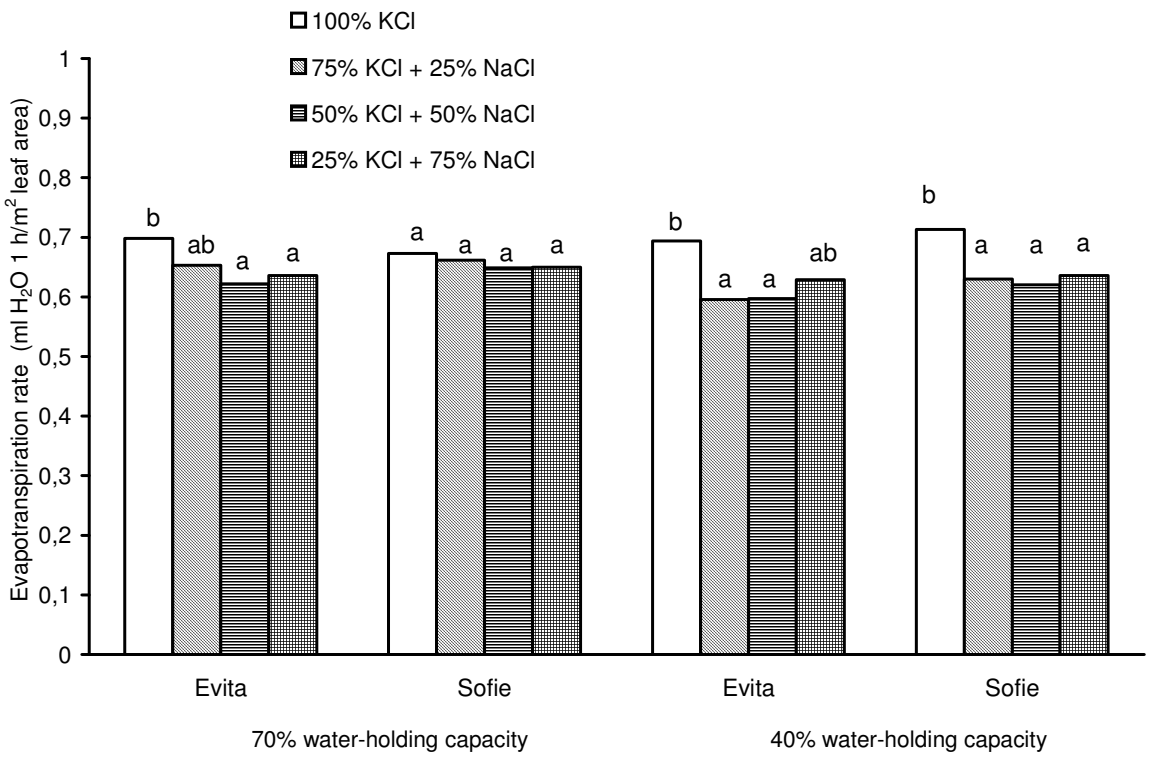

Fig. 24: Effect of water stress and K^+ substitution by Na^+ on the evapotranspiration rate of two sugar beet cultivars grown in soil under natural conditions for 3 months

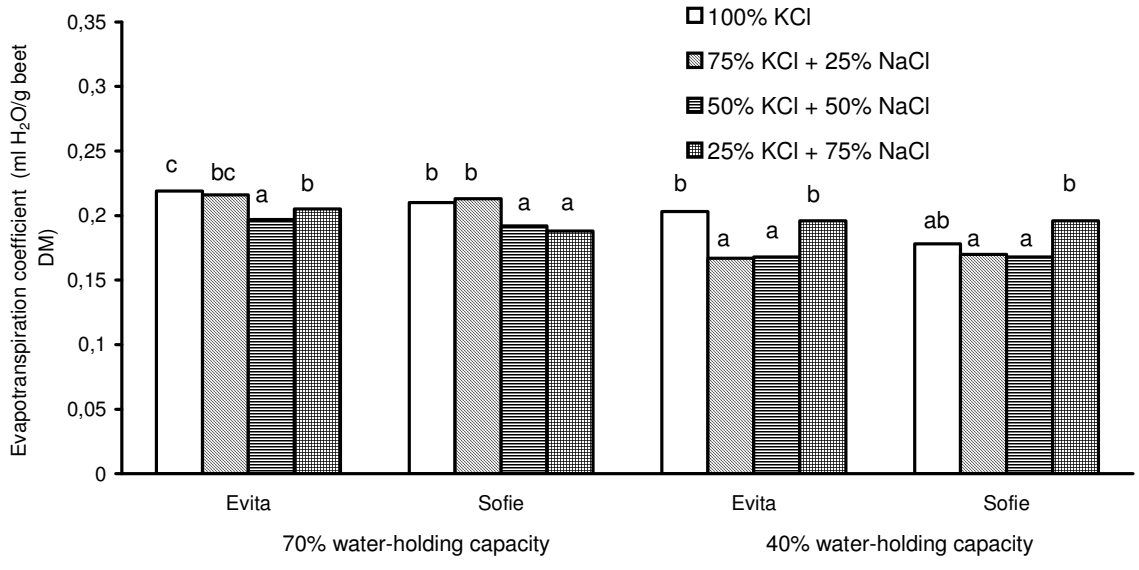

Fig. 25: Effect of water stress and K^+ substitution by Na^+ on the evapotranspiration coefficient of beets of two sugar beet cultivars grown in soil under natural conditions for 3 months

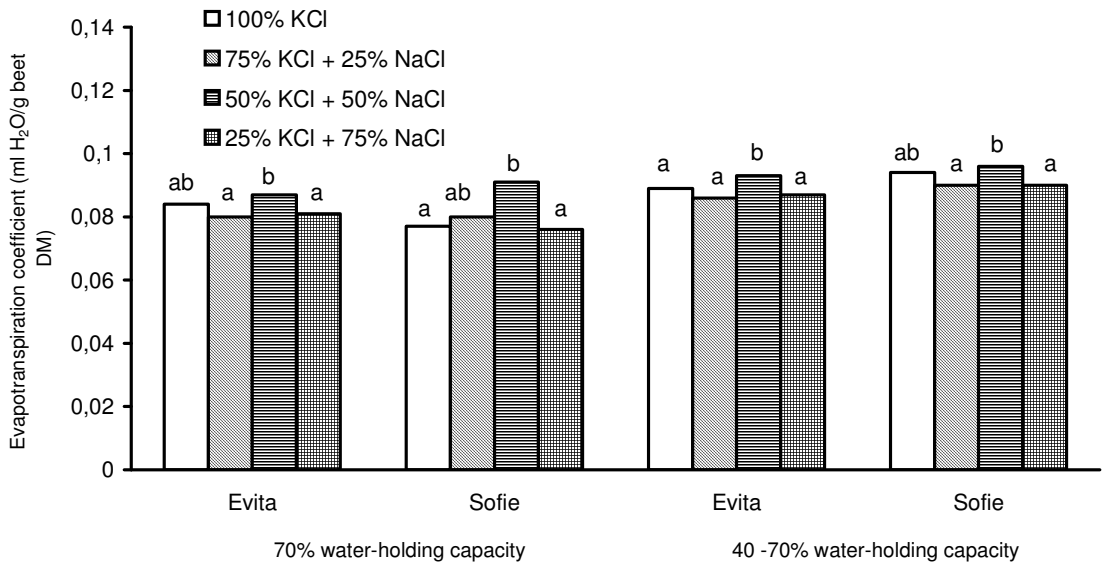

Fig. 26: Effect of water stress and K^+ substitution by Na^+ on the evapotranspiration coefficient of beet of two sugar beet cultivars grown in soil under natural conditions for 6 months

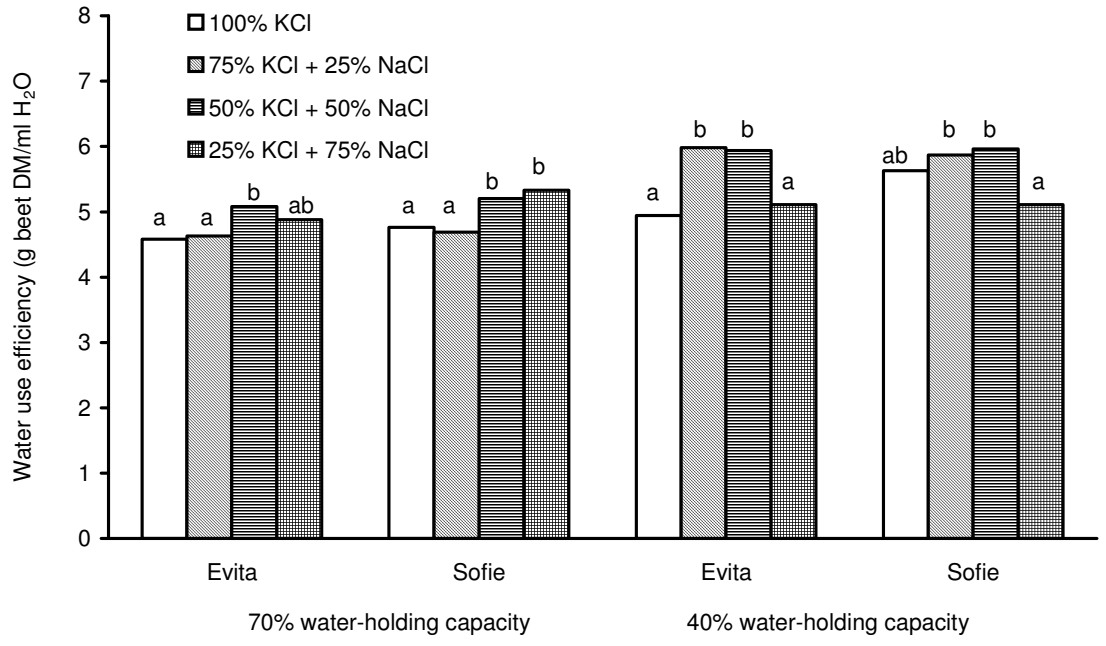

Fig. 27: Effect of water stress and K^+ substitution by Na^+ on the water use efficiency of two sugar beet cultivars grown in soil under natural conditions for 3 months

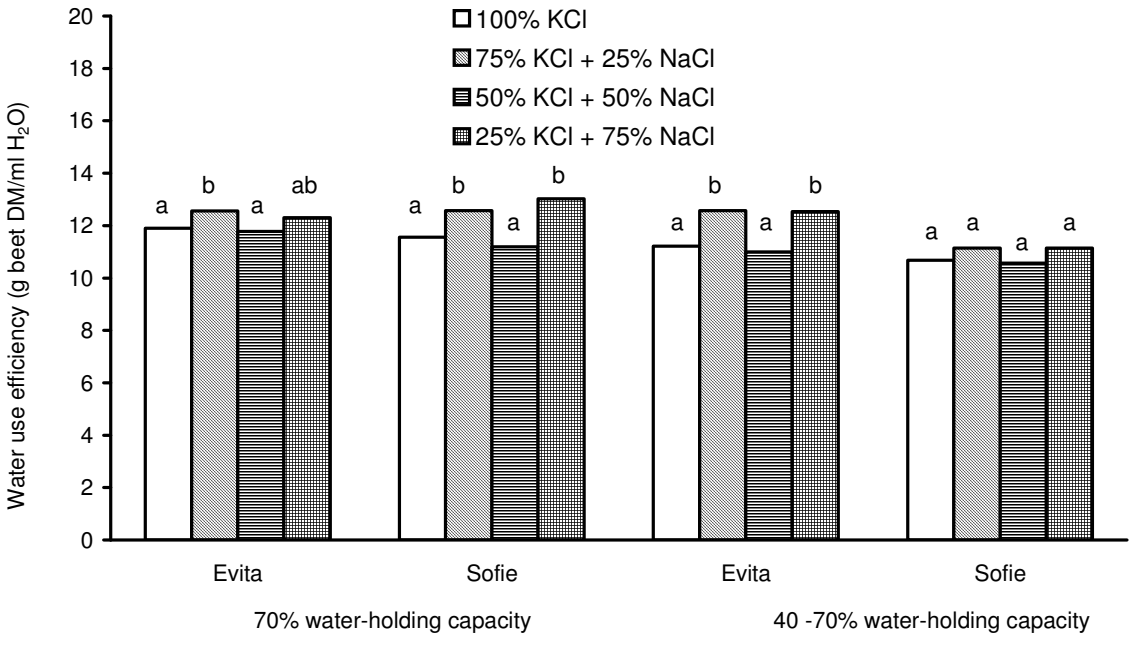

Fig. 28: Effect of water stress and K^+ substitution by Na^+ on the water use efficiency of two sugar beet cultivars grown in soil under natural conditions for 6 months

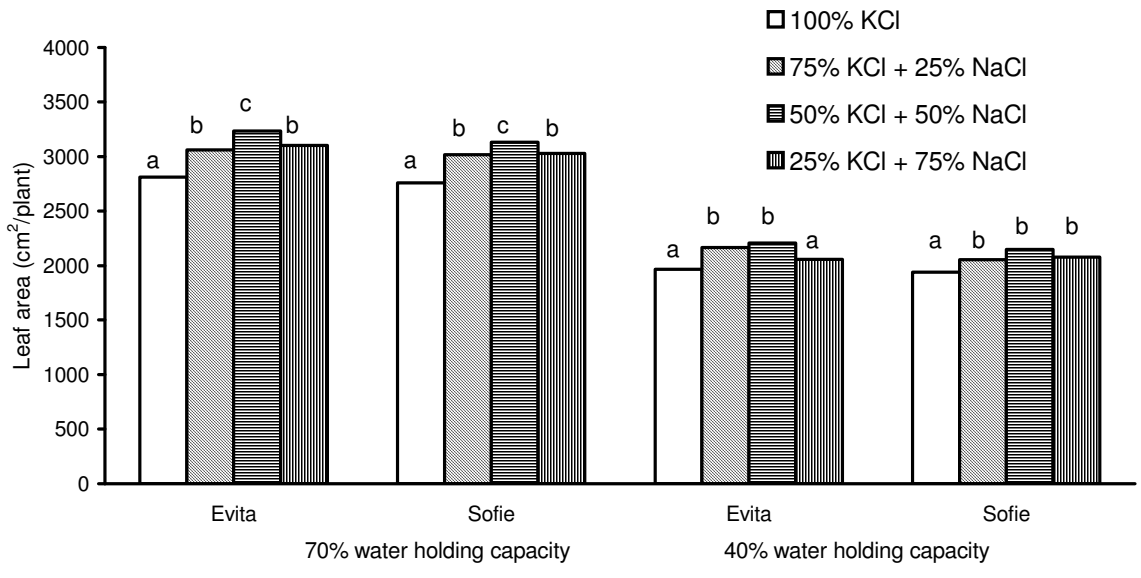

Fig. 29: Effect of water stress and K^+ substitution by Na^+ on the leaf area of two sugar beet cultivars grown in soil under natural conditions for 3 months

Tables 10 and 11 present the cation concentrations of leaves and beets. In general, the cation concentrations were higher in the plants under water stress (40% WHC) relative to 70% WHC treatment. Leaf K^+ concentrations decreased significantly due to increased K^+ substitution by Na^+ for both cultivars under two water treatments for both harvests (Table 10). At the first harvest, beet K^+ concentrations were reduced significantly in all treatments of K^+ substitution by Na^+ for both cultivars at 70 and 40% WHC. At the second harvest, beet K^+ concentrations decreased significantly at 75% K^+ substitution for both cultivars at only 70% WHC (Table 11). In contrast to the K^+ concentrations, the Na^+ concentrations of leaves and beets were significantly increased due to increased K^+ substitution by Na^+ for both cultivars under two water treatments for both harvests (Table 10 and 11). Leaf Ca^{2+} concentrations were reduced by increased K^+ substitution for both cultivars under two water treatments at the first harvest. Similarly, at the second harvest, leaf Ca^{2+} concentrations decreased significantly only at 75% K^+ substitution for both cultivars under two water treatments. At the first harvest, beet Ca^{2+} concentrations decreased significantly only at 75% K^+ substitution for cultivar Evita at 70% WHC and for cultivar Sofie at 40% WHC treatment. At the second harvest, the reduction of beet Ca^{2+} concentrations was not significant in all treatments of K^+ substitution for two cultivars. Leaf Mg^{2+} concentrations at the first harvest was significantly decreased by increasing K^+ substitution for both cultivars only under water stress. At the second harvest, Mg^{2+} concentrations of leaves were reduced significantly in all treatments of K^+ substitution only for cultivar Sofie under water stress. Beet Mg^{2+} concentrations at the second harvest, increased significantly in all treatments of K^+ substitution for cultivar Sofie under 70% WHC (Table 10 and 11). At the first harvest, Cl^- concentrations of leaves decreased significantly at 50% K^+ substitution only for cultivar Sofie under both water treatments. No significant effect on leaf Cl^- concentrations were observed under two water treatments at the second harvest. Beet Cl^- concentrations at the first harvest were not significantly affected under both water treatments. At the second harvest, beet Cl^- concentrations decreased significantly at 75% K^+ substitution for both cultivars under 70% WHC (Table 12).

In Table 12, α-amino-N concentrations of leaves and beets are documented. After three months of growth, leaf α-amino-N concentrations were slightly influenced by water stress and K^+ substitution by Na^+. At the final harvest, the α-amino-N concentrations of leaves and beets were increased significantly at 50 and 75% K^+ substitution for both cultivars. It is evident that the highest increment of α-amino-N concentrations was obtained with the treatment with 50% K^+ substitution for both cultivars (Table 12).

Table 10: Effect of water stress and K^+/Na^+ substitution on the cation concentrations of leaves (mg/g DW) of two sugar beet cultivars grown in soil under natural conditions for 3 and 6 months, respectively

Treatments	First harvest															
	70% water-holding capacity								40% water-holding capacity							
	Evita				Sofie				Evita				Sofie			
	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}
100% KCl Control	46.9 d	5.60 a	16.7 b	15.6 b	51.6 d	6.8 a	17.1 b	13.9 a	53.5 d	5.7 a	17.3 c	18.2 b	59.0 d	6.6 a	17.5 c	16.2 c
75% KCl + 25% Nacl	35.9 c	11.5 b	15.4 a	13.9 a	37.4 c	11.5 b	16.0 a	13.7 a	48.2 c	10.4 b	16.3 bc	17.0 a	52.7 c	11.5 b	16.3 b	14.6 a
50% KCl + 50% NaCl	30.3 b	14.4 c	17.0 b	14.9 b	32.2 b	17.0 c	15.0 a	13.5 a	39.4 b	15.7 c	14.1 a	17.0 a	39.8 b	16.7 c	16.5 bc	15.9 bc
25% KCl + 75% NaCl	22.1 a	19.3 d	15.4 a	14.4 ab	21.2 a	21.4 d	16.2 a	14.8 b	33.7 a	17.9 d	15.3 b	16.9 a	31.6 a	19.0 d	14.5 a	15.6 b
L.S.D 5%	3.1	0.96	1.28	0.96					3.25	1.1	1.1	0.91				
	Second harvest															
	70% water-holding capacity								40 -70% water-holding capacity							
100% KCl Control	43.9 c	4.5 a	25.7 b	20.0 a	47.7 c	5.9 a	26.0 b	20.6 c	48.4 d	6.2 a	19.3 b	18.6 b	48.3 d	5.4 a	20.2 b	19.4 c
75% KCl + 25% Nacl	38.9 b	13.0 b	23.9 b	19.8 a	39.7 b	12.3 b	24.1 b	19.1 b	43.8 c	13.0 b	20.5 b	17.9 ab	41.6 c	12.0 b	19.1 b	17.9 b
50% KCl + 50% NaCl	24.6 a	17.4 c	21.5 a	18.8 a	24.4 a	18.6 c	22.3 ab	19.0 b	29.9 b	20.4 c	21.2 b	17.7 ab	26.1 b	20.0 c	19.1 b	17.8 b
25% KCl + 75% NaCl	22.3 a	25.6 d	22.1 ab	19.2 a	21.1 a	25.7 d	20.6 a	17.1 a	22.3 a	26.8 d	17.5 a	17.0 a	18.9 a	27.0 d	16.8 a	16.2 a
L.S.D 5%	3.75	1.34	2.0	1.49					3.52	2.14	2.0	1.51				

Critical values of cation concentrations according to Bergmann (1992):
35- 60 mg K^+/g DW
7-20 mg Ca^{2+}/g DW
3-7 mg Mg^{2+}/g DW

Table 11: Effect of water stress and K^+/Na^+ substitution on the cation concentrations of beets (mg/g DW) of two sugar beet cultivars grown in soil under natural conditions for 3 and 6 months, respectively

Treatments	First harvest															
	70% water-holding capacity								40% water-holding capacity							
	Evita				Sofie				Evita				Sofie			
	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}
100% KCl Control	8.8 d	0.26 a	1.3 b	1.8 a	8.93 d	0.33 a	1.2 a	1.6 a	10.0 c	0.23 a	1.3 b	1.6 b	9.5 d	0.24 a	1.3 b	1.4 a
75% KCl + 25% Nacl	8.5 c	0.36 b	1.1 a	1.7 a	8.32 c	0.39 a	1.2 a	1.5 a	8.5 b	0.29 a	1.2 b	1.5 ab	9.1 c	0.31 b	1.2 b	1.4 a
50% KCl + 50% NaCl	7.4 b	0.50 c	1.3 b	1.7 a	7.62 b	0.72 b	1.2 a	1.6 a	8.6 b	0.46 b	1.3 b	1.6 a	8.9 b	0.43 c	1.2 b	1.4 a
25% KCl + 75% NaCl	7.0 a	0.75 d	1.2 a	1.7 a	7.18 a	0.85 c	1.3 a	1.7 b	7.3 a	0.45 b	1.1 b	1.4 b	7.3 a	0.45 c	1.0 a	1.3 a
L.S.D 5%	0.16	0.09	0.15	0.15					0.21	0.07	0.11	0.13				
	Second harvest															
	70% water-holding capacity								40 -70% water- holding capacity							
100% KCl Control	5.3 b	0.12 a	1.36 a	1.33 a	5.68 b	0.12 a	1.22 a	1.24 a	6.57 a	0.13 a	1.27 b	1.50 a	6.41 a	0.17 a	1.30 a	1.49 a
75% KCl + 25% Nacl	5.3 b	0.14 a	1.30 a	1.39 a	5.14 a	0.14 a	1.19 a	1.37 b	6.57 a	0.21 a	1.28 b	1.52 a	6.48 a	0.30 b	1.21 a	1.56 a
50% KCl + 50% NaCl	5.5 b	0.24 b	1.17 a	1.35 a	5.57 ab	0.25 b	1.13 a	1.38 b	6.59 a	0.35 b	1.14 b	1.49 a	6.71 ab	0.41 c	1.16 a	1.49 a
25% KCl + 75% NaCl	4.8 a	0.30 b	1.03 a	1.33 a	4.82 a	0.25 b	1.11 a	1.36 b	6.66 a	0.41 b	1.06 a	1.44 a	6.98 b	0.43 c	1.15 a	1.50 a
L.S.D 5%	0.5	0.08	0.16	0.12					0.44	0.09	0.22	0.25				

Table 12: Effect of water stress and K^+/Na^+ substitution on Cl^- and α-amino-N concentrations of plants of two sugar beet cultivars grown in soil under natural conditions for 3 and 6 months, respectively

Treatments	Cl^- concentrations (mg/g DW)															
	First harvest								Second harvest							
	70% water-holding capacity				40% water-holding capacity				70% water-holding capacity				40 -70% water-holding capacity			
	Leaves		Beets		Leaves		Beets		Leaves		Beets		Leaves		Beets	
	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie
100% KCl Control	17.33 a	20.69 b	2.69 a	2.55 a	16.99 a	20.01 b	2.83 a	2.61 a	28.87 a	29.90 a	2.62 b	2.71 b	29.88 a	29.79 a	2.43 a	2.54 a
75% KCl + 25% Nacl	18.46 ab	19.57 ab	2.79 a	2.69 a	17.07 a	19.33 ab	2.77 a	2.58 a	29.23 a	30.62 a	2.74 b	2.56 a	29.07 a	28.39 a	2.52 a	2.55 a
50% KCl + 50% NaCl	17.40 a	18.88 a	2.71 a	2.52 a	17.98 a	18.40 a	2.81 a	2.50 a	27.49 a	30.31 a	2.65 b	2.59 b	28.79 a	28.17 a	2.49 a	2.64 ab
25% KCl + 75% NaCl	18.94 b	19.95 ab	2.75 a	2.47 a	17.29 a	18.20 a	2.70 a	2.47 a	27.03 a	28.87 a	2.53 a	2.44 a	29.77 a	27.39 a	2.74 b	2.72 b
L.S.D 5%	1.56		0.23		1.47		0.17		2.43		0.13		2.42		0.15	
	α-amino-N concentrations (mmol/kg DW)															
	70% water-holding capacity				40% water-holding capacity				70% water-holding capacity				40 -70% water-holding capacity			
	Leaves		Beets		Leaves		Beets		Leaves		Beets		Leaves		Beets	
	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie	Evita	Sofie
100% KCl Control	44.53 a	45.70 a	16.29 a	16.92 a	47.42 a	48.15 a	18.10 a	19.46 a	21.81 a	22.72 a	13.18a	14.75 a	21.27 a	22.90 a	15.66 a	16.29 a
75% KCl + 25% Nacl	44.80 a	45.97 a	16.47 a	17.47 a	47.97 a	48.96 a	20.91 b	20.18 a	22.99 a	23.53 a	13.94 a	15.20 a	22.80 a	23.50 a	16.20 a	18.55 b
50% KCl + 50% NaCl	45.34 a	47.33 ab	18.37 ab	19.91 b	49.78 b	49.59 a	22.81 c	23.08 b	25.07 b	26.43 b	15.57 b	16.92 b	25.61 b	26.15 b	22.35 b	23.98 d
25% KCl + 75% NaCl	48.06 b	48.33 b	17.38 ab	18.73 ab	48.06 ab	48.87 a	19.19 a	20.36 a	25.61 b	26.25 b	17.83 c	17.27 b	24.34 b	25.07 b	21.81 b	22.35 c
L.S.D 5%	2.47		2.15		2.23		1.53		1.77		1.416		1.22		1.17	

The sucrose concentrations (mg/g DW) of beets increased significantly under water stress compared to 70% WHC. Moreover, at the first harvest, sucrose concentrations were significantly higher in all treatments of K^+ substitution by Na^+ compared to 100% KCl for both cultivars under water stress. The higher sucrose concentrations were obtained at 50% K^+ substitution for both cultivars (Fig. 30). However, at the second harvest, the difference was not significant among all the treatments of K^+ substitution (Fig. 31). At the first harvest, sucrose concentrations (expressed as % FW) increased significantly at 50% K^+ substitution for both cultivars under two water treatments. However, it was significantly reduced at 75% K^+ substitution only for cultivar Sofie under water stress (Fig. 32). At the second harvest, sucrose concentrations (%FW) increased significantly only with 75% K^+ substitution for cultivar Evita at 70% WHC (Fig. 33). Sugar yield at the first harvest was significantly increased at 50 and 75% K^+ substitution compared to 100% KCl for both cultivars at 70% WHC. Under water stress increase in sugar yield was significant at 25 and 50% K^+ substitution for the two cultivars (Fig. 34). At the second harvest, sugar yield increased significantly in all treatments of K^+ substitution for both cultivars at 70% WHC (Fig. 35). White sugar yield increased significantly in all treatments of K^+ substitution compared to 100% KCl for two cultivars at 70% WHC at both harvests. Under water stress, 25 and 50% K^+ substitution significantly increase white sugar yield of both cultivars (Fig. 36 and 37).

The analysis of variance, presented in Table 13-16 revealed that water stress had a strong effect on all plant growth parameters (leaf fresh and dry weights and beet fresh and dry weights). The effects of K^+ substitution by Na^+ treatments are stronger on such parameters than the genotype. The same trend was observed for the other parameters (cations, α-amino-N, sugar concentrations and water relations).

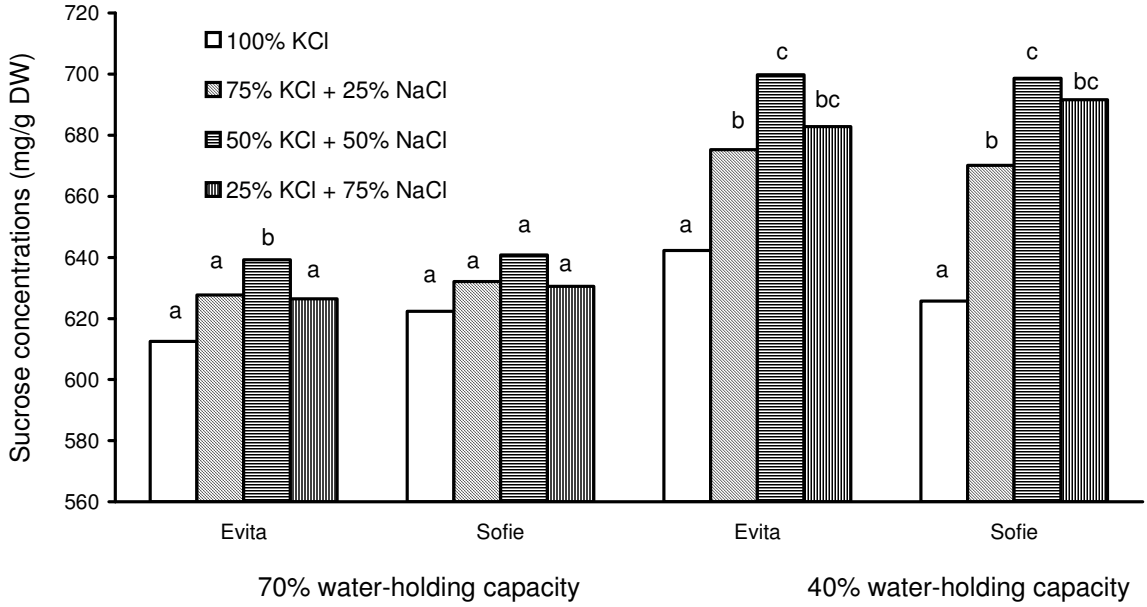

Fig. 30: Effect of water stress and K^+ substitution by Na^+ on the sucrose concentrations of beets of two sugar beet cultivars grown in soil under natural conditions for 3 months

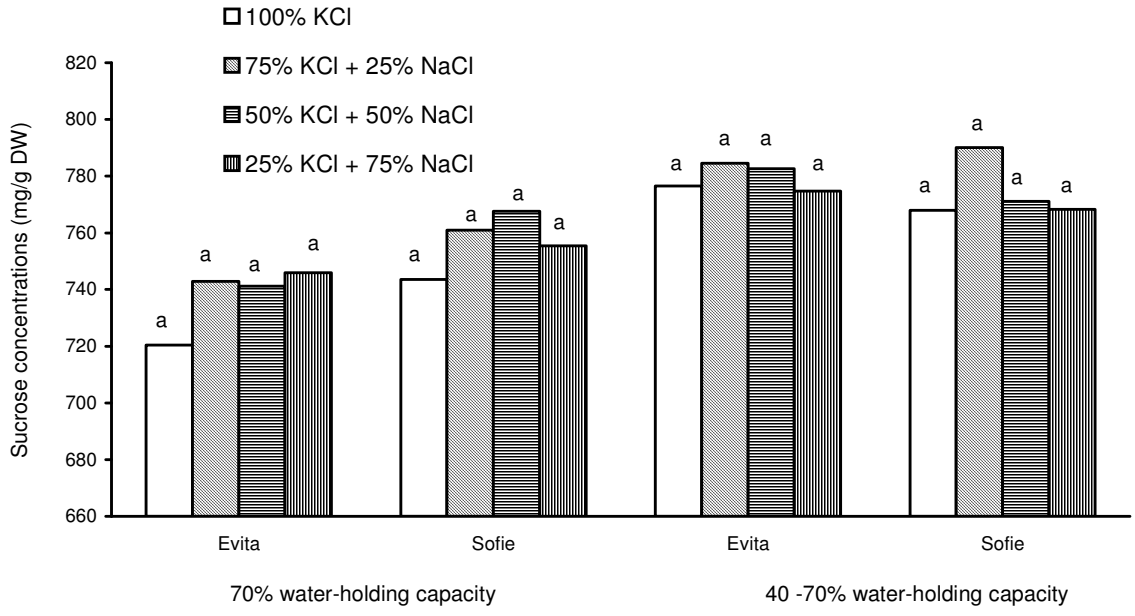

Fig. 31: Effect of water stress and K^+ substitution by Na^+ on the sucrose concentrations of beets of two sugar beet cultivars grown in soil under natural conditions for 6 months

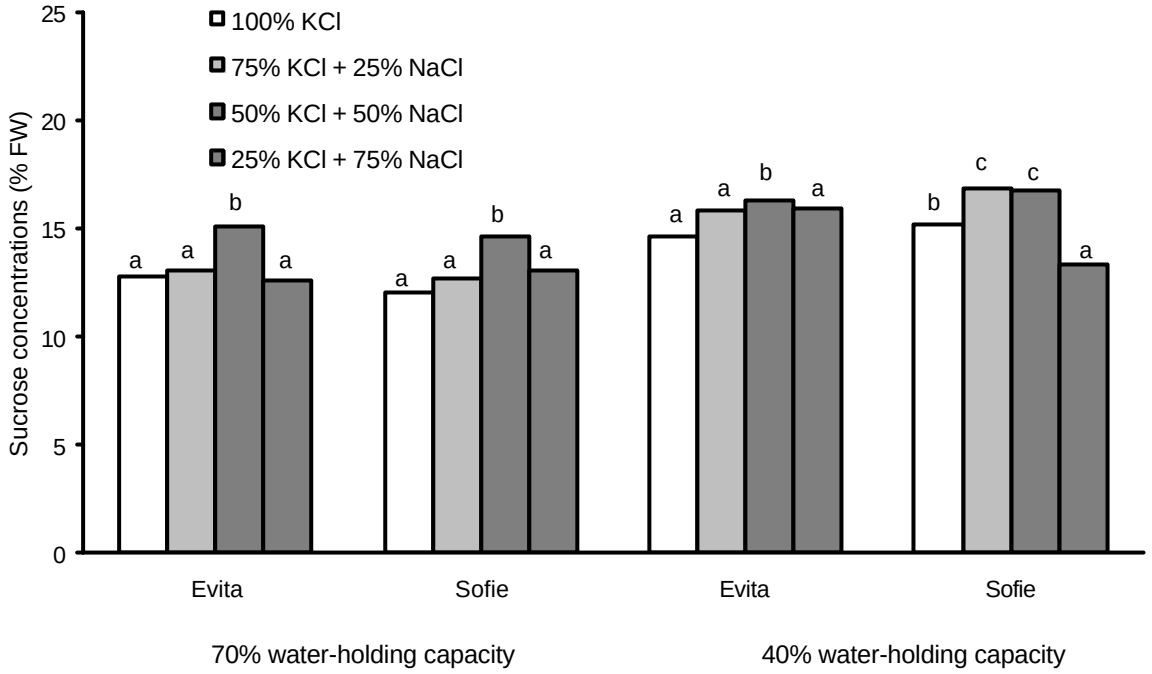

Fig. 32: Effect of water stress and K^+ substitution by Na^+ on the sucrose concentrations of beets of two sugar beet cultivars grown in soil under natural conditions for 3 months

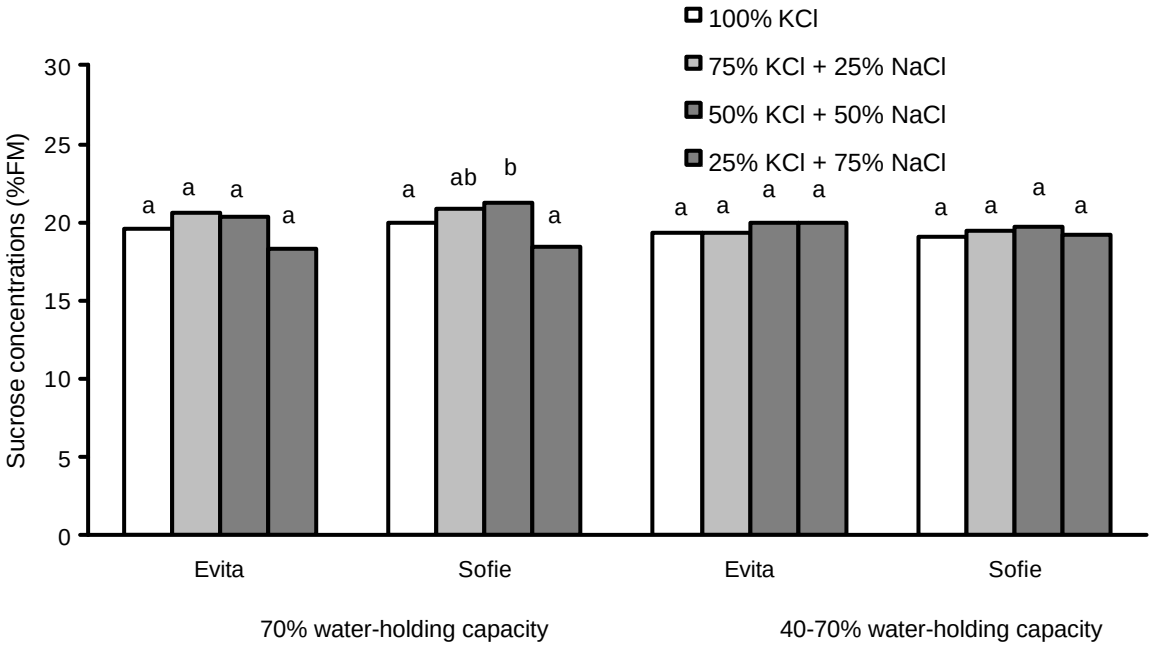

Fig. 33: Effect of water stress and K^+ substitution by Na^+ on the sucrose concentrations of beets of two sugar beet cultivars grown in soil under natural conditions for 6 months

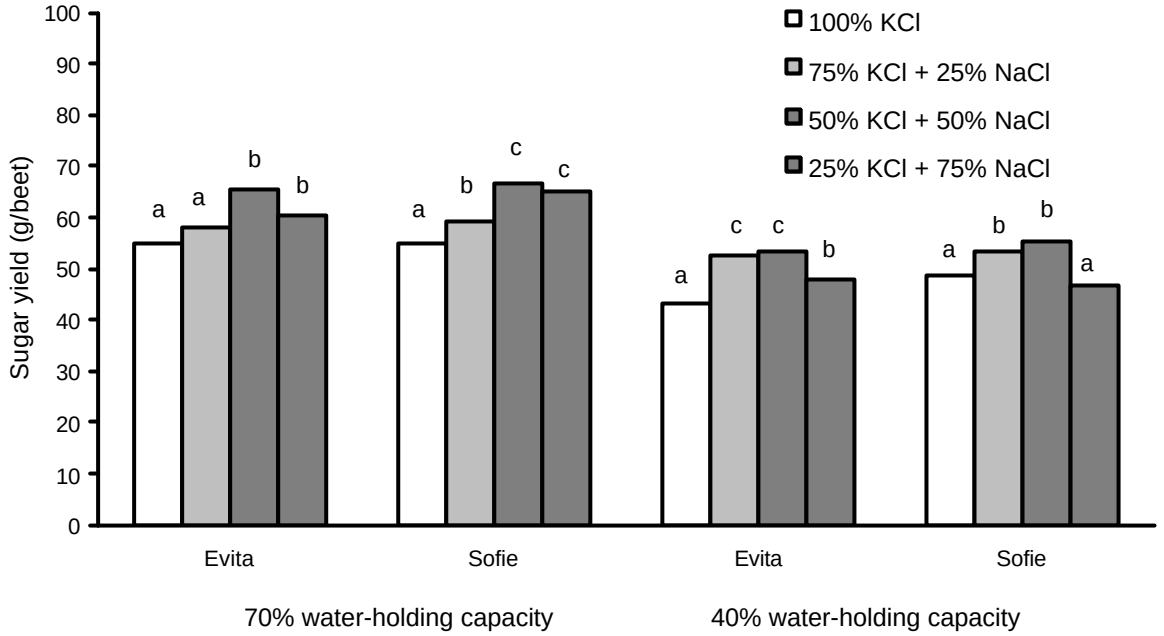

Fig. 34: Effect of water stress and K^+ substitution by Na^+ on the sugar yield of beets of two sugar beet cultivars grown in soil under natural conditions for 3 months

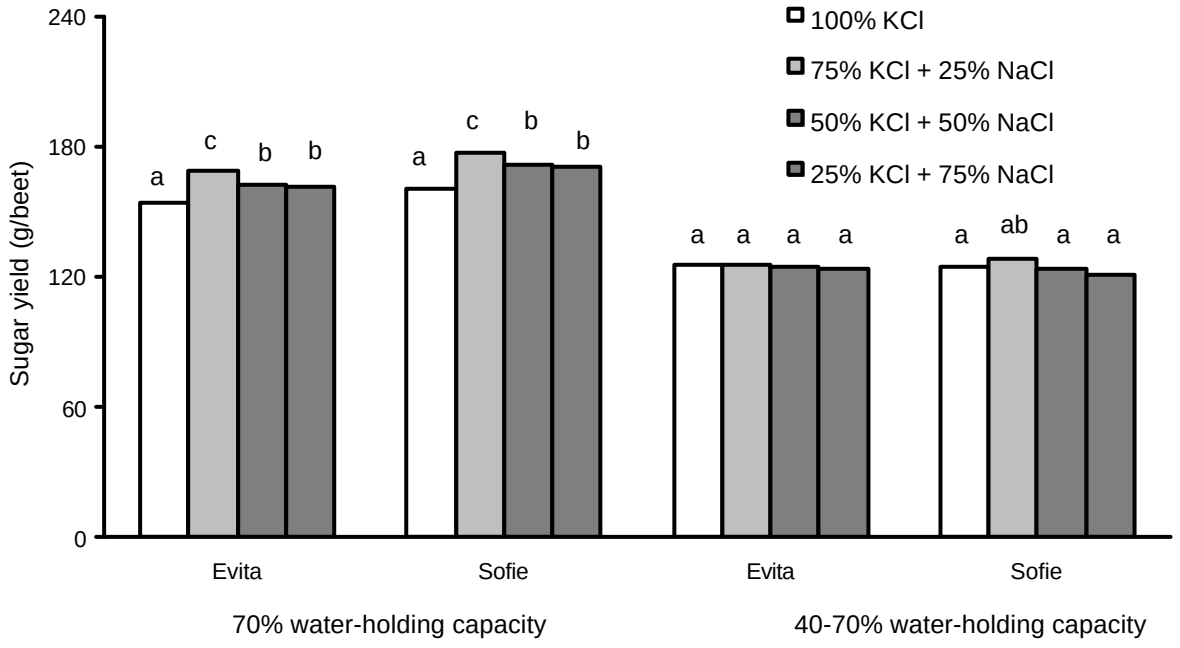

Fig. 35: Effect of water stress and K^+ substitution by Na^+ on the sugar yield of beets of two sugar beet cultivars grown in soil under natural conditions for 6 months

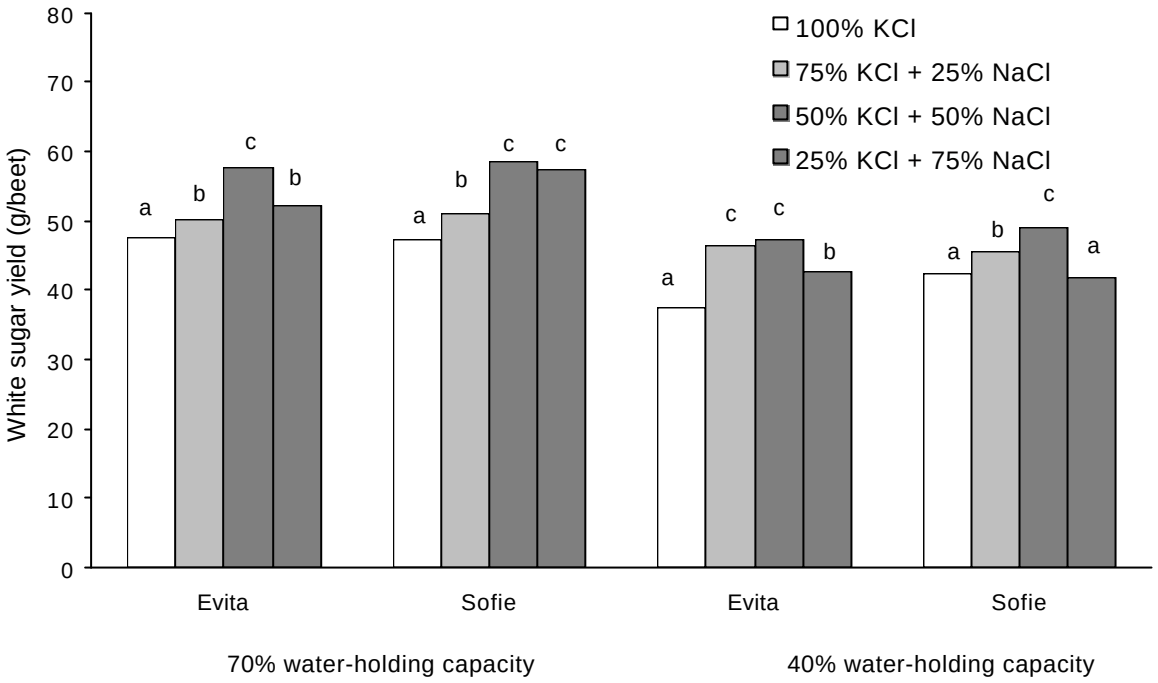

Fig. 36: Effect of water stress and K^+ substitution by Na^+ on the white sugar yield of two sugar beet cultivars grown in soil under natural conditions for 3 months

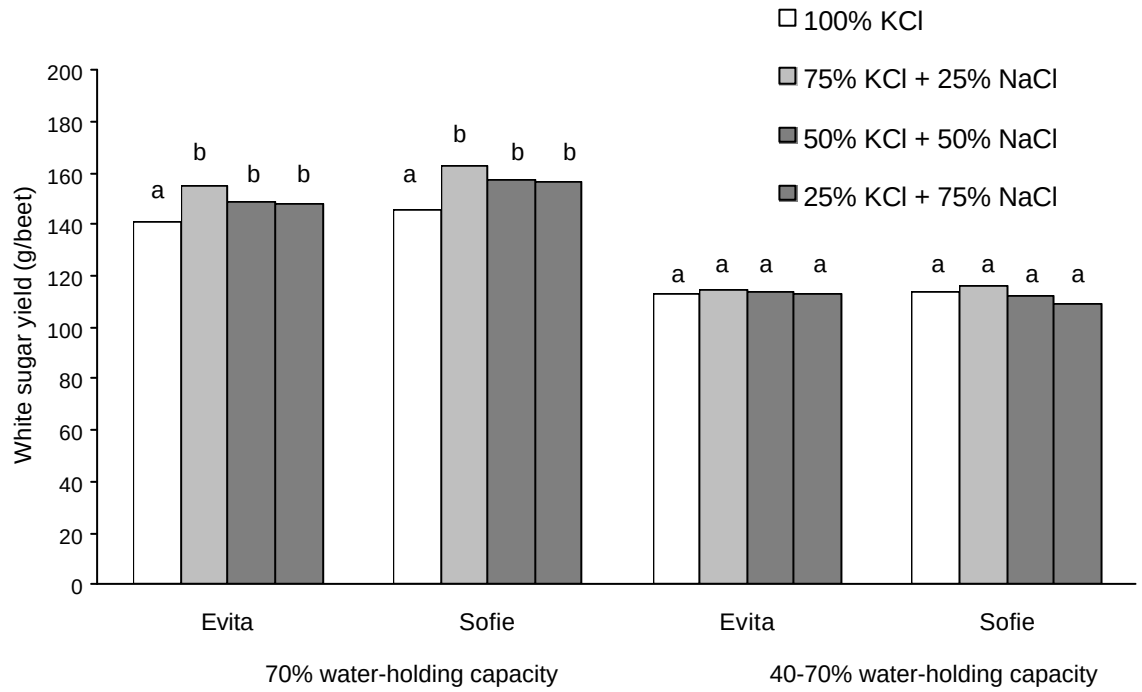

Fig. 37: Effect of water stress and K^+ substitution by Na^+ on the white sugar yield of beets of two sugar beet cultivars grown in soil under natural conditions for 6 months

Table 13: Analysis of variance of water stress and K^+/Na^+ substitution on plant growth of two sugar beet genotypes grown in soil under natural conditions for 3 and 6 months, respectively

Source	First harvest							
	Leaf fresh weight		Leaf dry weight		Beet fresh weight		Beet dry weight	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Genotype	1098.3	13.1**	61.6	16.7**	3390.7	16.1**	180.6	5.7*
Treatment	1838.8	21.9**	6.8	1.8 NS	4756.4	22.6**	394.2	12.5**
Water stress	176929	2103**	1343.2	365.1**	361722	1718**	10525	334.0**
Error	84.1		3.7		210.5		31.5	
	Second harvest							
Genotype	19.4	0.19 NS	0.54	0.18 NS	8903.8	7.8*	406.9	5.2*
Treatment	420.5	4.2*	9.29	3.2*	5406.9	4.7*	528.4	6.8*
Water stress	542.2	5.4*	0.35	0.12 NS	771758	676.5**	78926	1009.5**
Error	99.8		2.9		1140.8		78.2	

Table 14: Analysis of variance of water stress and K^+/Na^+ substitution on cation concentrations of two sugar beet genotypes grown in soil under natural conditions for 3 and 6 months, respectively

Source	Leaves				Beet			
	First harvest							
	K^+		Na^+		K^+		Na^+	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean square	F-Ratio	Mean Square	F-Ratio
Genotype	73.54	9.61*	31.78	38.86**	0.18	0.69 NS	0.06	7.92*
Treatment	2406.1	314.5**	666.41	814.8**	15.68	61.21**	0.55	75.5**
Water stress	2017	263.7**	5.29	6.44*	8.7	34.02**	0.52	71.44**
Error	7.65		0.82		0.26		0.01	
	Ca^{2+}		Mg^{2+}		Ca^{2+}		Mg^{2+}	
Genotype	2.24	0.80 NS	29.53	47.41**	0.001	0.01 NS	0.27	23.78**
Treatment	52.35	12.59**	4.32	6.94**	0.05	3.68*	0.03	2.63 NS
Water stress	1.35	0.35 NS	87.36	140.3**	0.04	3.01 NS	1.19	103**
Error	0.99		0.62		0.01		0.01	
	Second harvest							
	K^+		Na^+		K^+		Na^+	
Genotype	12.48	1.34 NS	2.1	0.55 NS	0.03	0.18 NS	0.01	2.65 NS
Treatment	2968.4	318.66**	1494.6	393.7**	0.28	1.58 NS	0.19	51.62**
Water stress	92.45	9.92*	9.28	2.44 NS	35.52	202.3 NS	0.23	60.88**
Error	9.32		3.8		0.18		0.04	
	Ca^{2+}		Mg^{2+}		Ca^{2+}		Mg^{2+}	
Genotype	3.64	0.99 NS	1.06	0.79 NS	0.01	0.33 NS	0.001	0.02 NS
Treatment	45.47	12.36**	17.17	12.84**	0.11	3.93*	0.017	0.79 NS
Water stress	333	90.52**	36.72	27.45**	0.34	12.13**	046	21.09**
Error	3.68		1.34		0.03		0.022	

Table 15: Analysis of variance of water stress and K^+/Na^+ substitution on α-amino-N concentrations, leaf area and water relations of two sugar beet genotypes grown in soil under natural conditions for 3 and 6 months, respectively

Source	First harvest					
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
	Leaf α-amino-N concentrations		Beet α-amino-N concentrations		Leaf area	
Genotype	15.12	5.15*	16.23	5.57*	60775.3	7.56*
Treatment	15.74	5.37**	39.83	13.67**	335416	41.74**
Water stress	109.65	37.37**	150.51	51.67**	1.77	2204.1**
Error	2.93		2.91		8036	
	Evapotranspiration		Evapotranspiration coefficient		Water use efficiency	
Genotype	42.34	4.25 NS	0.03	5.32*	24.27	2.53NS
Treatment	245.25	21.72*	0.42	61.25**	34.56	20.23*
Water stress	1927.21	253.3**	0.72	88.23**	15.17	8.24*
Error	47.27		0.01		1.23	
	Second harvest					
	Leaf α-amino-N concentrations		Beet α-amino-N concentrations		Evapotranspiration rate	
Genotype	15.6	8.62*	24.12	10.82*	0.07	4.13*
Treatment	59.49	32.87**	125.98	56.49**	0.34	52.16*
Water stress	2.31	1.28 NS	330.69	148.27**	0.83	130.14**
Error	1.91		2.23		0.04	
	Evapotranspiration		Evapotranspiration coefficient		Water use efficiency	
Genotype	34.14	6.13*	0.13	7.31*	37.52	3.72*
Treatment	179.18	15.26*	0.21	46.32**	60.24	42.43**
Water stress	1273.16	234.24**	0.36	62.13**	12.84	5.13*
Error	80.24		0.24		1.52	

Table 16: Analysis of variance of water stress and K^+/Na^+ substitution on sugar concentrations, sugar and white sugar yields of two sugar beet genotypes grown in soil under natural conditions for 3 and 6 months, respectively

Source	First harvest							
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
	Sucrose concentration		Sucrose % FW		Sugar yield		White sugar yield	
Genotype	10.73	0.03^{NS}	1.01	0.8^{NS}	74.5	6.2^{*}	83.6	9.5^{*}
Treatment	6884.8	18.8^{**}	22.8	17.4^{**}	321.9	26.8^{**}	337.1	38.1^{**}
Water stress	39298.5	107.2^{**}	135.8	104.0^{**}	2252.0	187.4^{**}	2545.1	287.9^{**}
Error	366.6		1.31		12.0		8.8	
	Second harvest							
	Sucrose concentration		Sucrose % FW		Sugar yield		White sugar yield	
Genotype	982.1	2.3^{NS}	1.0	0.9^{NS}	393.1	11.8^{*}	575.6	10.4^{*}
Treatment	1115.2	2.6^{NS}	10.0	9.1^{**}	291.5	8.8^{**}	354.6	6.4^{**}
Water stress	17704.2	41.1^{**}	5.8	5.3^{*}	34829.3	1048.8^{**}	36178.3	654.8^{**}
Error	431.06		1.1		33.2			55.3

4.1.3 Effect of drought and heat on the growth and sugar storage of two sugar beet cultivars grown in growth chambers

It is evident that the fresh and dry weights of leaves and beets were more affected by heat than drought (Photo 1). Furthermore, a significantly decreased plant growth was observed under 40% WHC compared to 70% WHC for both cultivars. Leaf and beet fresh weight decreased significantly under drought at high temperature for both cultivars. At low temperature, the effect of drought was not significant on fresh weight of leaves and beets for cultivar Evita, but this reduction was observed for cultivar Sofie (Fig. 38-40). No significant effect of drought treatment was observed on the dry weight of leaves at high temperature for both cultivars (Fig. 39). Beet dry weight decreased significantly in all treatments of drought and heat for cultivar Evita. The effect of two water treatments was not significant for cultivar Sofie at low temperature (Fig. 41).

Evapotranspiration (ET) increased significantly at high temperature compared to low temperature for both cultivars, whereas no significant affect was observed between two water treatments for both temperatures (Fig. 42). At high temperature conditions, the evapotranspiration rate (ER) and evapotranspiration coefficient (EC) were significantly higher under 40% WHC compared to 70% WHC (Fig. 43 and 44). On the other hand, water use efficiency of beets (WUE) was significantly reduced at high temperature relative to low temperature for both cultivars. Moreover, WUE was considerably reduced under drought compared to the 70% WHC for two temperature treatments (Fig. 45).

Leaf K^+ concentrations decreased significantly by heat only under water stress treatments for two cultivars. In beet there was a significant decrease with heat at 70% WHC only for cultivar Sofie. At high temperature leaf Na^+ concentrations were reduced significantly by water stress for cultivar Evita and with both water treatments for cultivar Sofie. No significant effect on Na^+ concentrations of beets were observed in all treatments for both cultivars (Table 17).

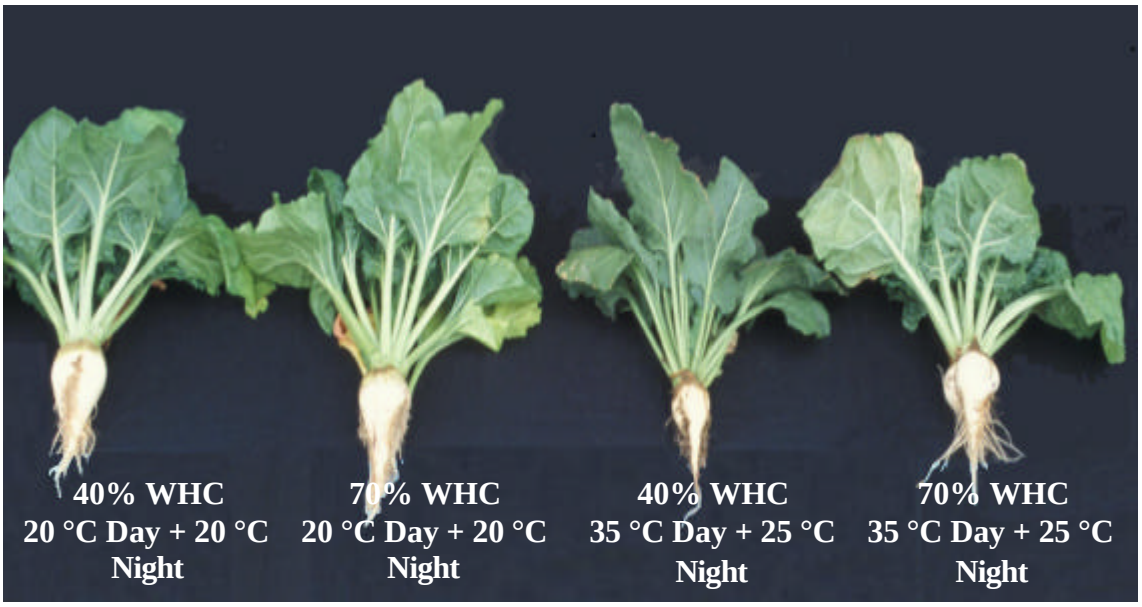

Photo 1 Effect of drought and heat on the growth of sugar beet plants (cv. Evita) grown in growth chambers for 10 weeks

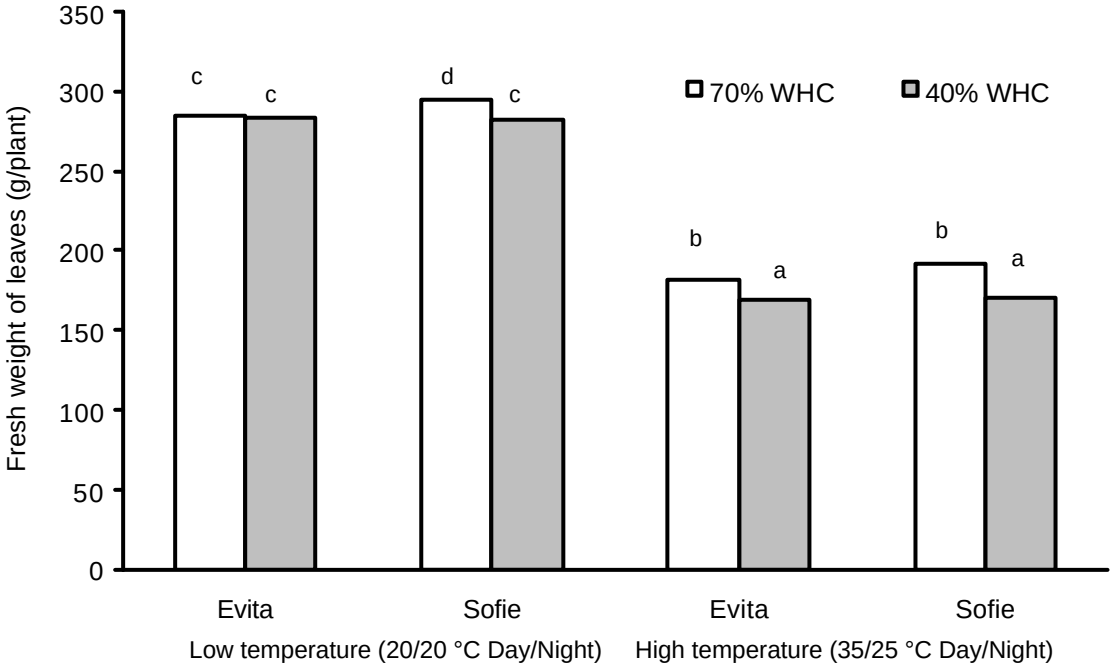

Fig. 38: Effect of drought and heat on the fresh weight of leaves of two sugar beet cultivars grown in growth chambers for 10 weeks

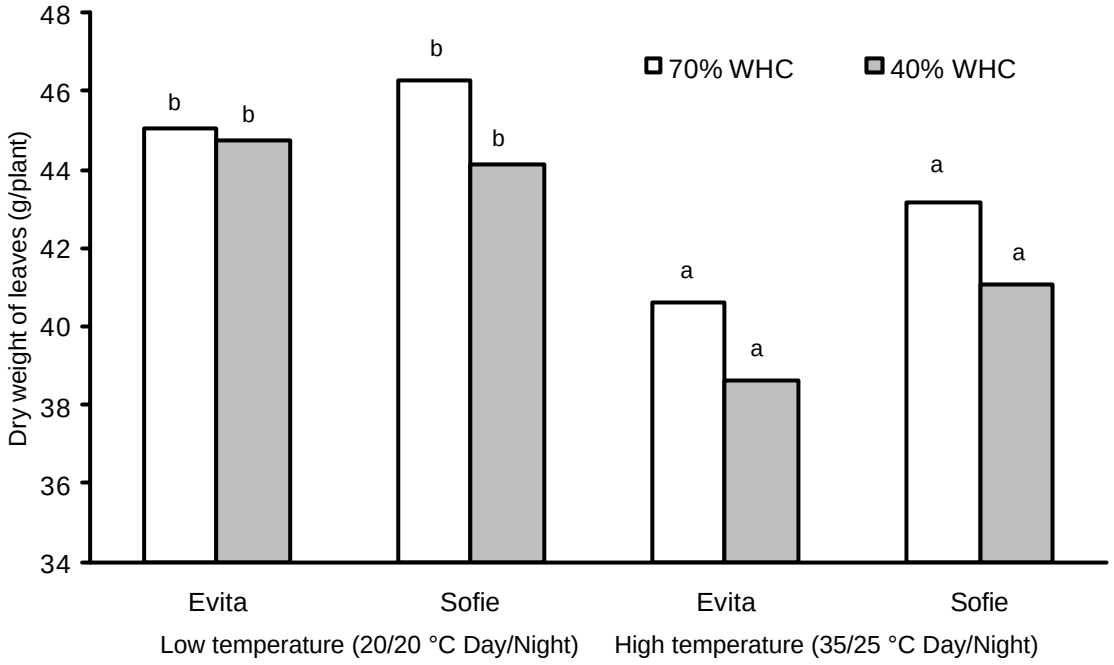

Fig. 39: Effect of drought and heat on the dry weight of leaves of two sugar beet cultivars grown in growth chambers for 10 weeks

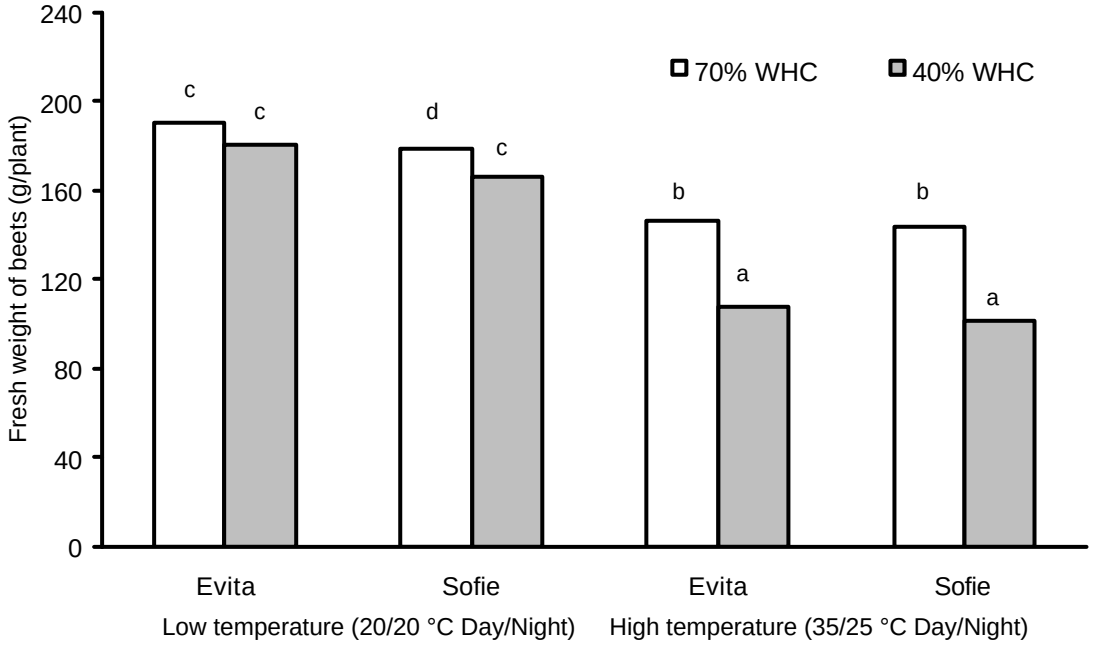

Fig. 40: Effect of drought and heat on the fresh weight of beets of two sugar beet cultivars grown in growth chambers for 10 weeks

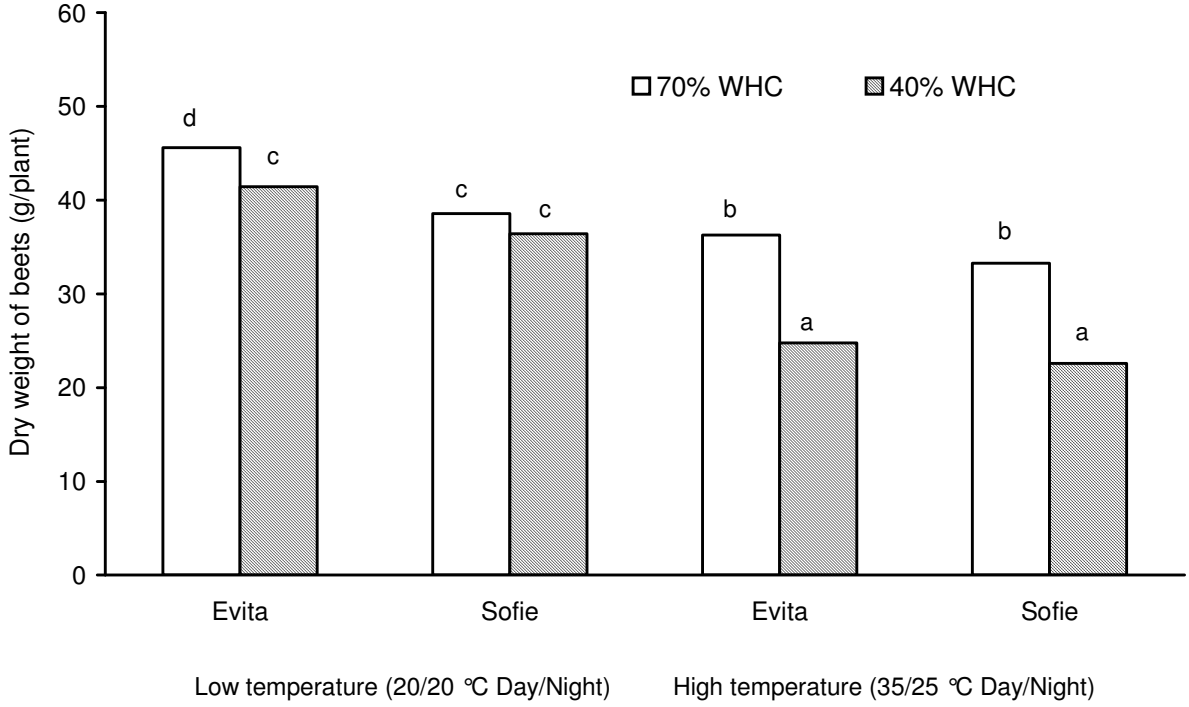

Fig. 41: Effect of drought and heat on the dry weight of beets of two sugar beet cultivars grown in soil in growth chambers for 10 weeks

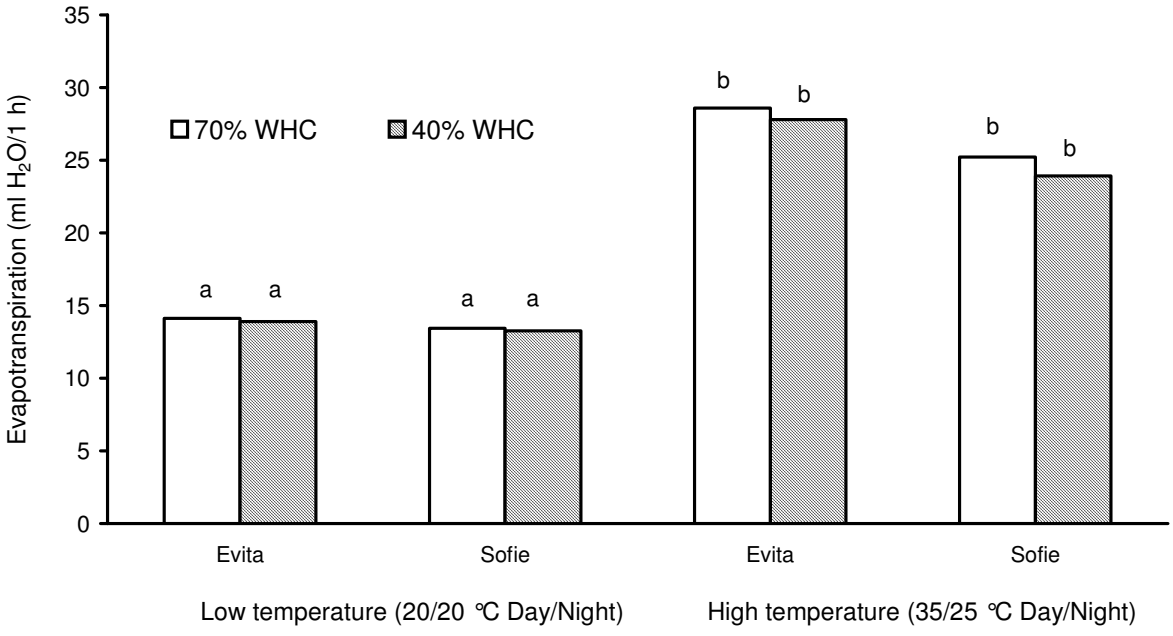

Fig. 42: Effect of drought and heat on the evapotranspiration of two sugar beet cultivars grown in soil in growth chambers for 10 weeks

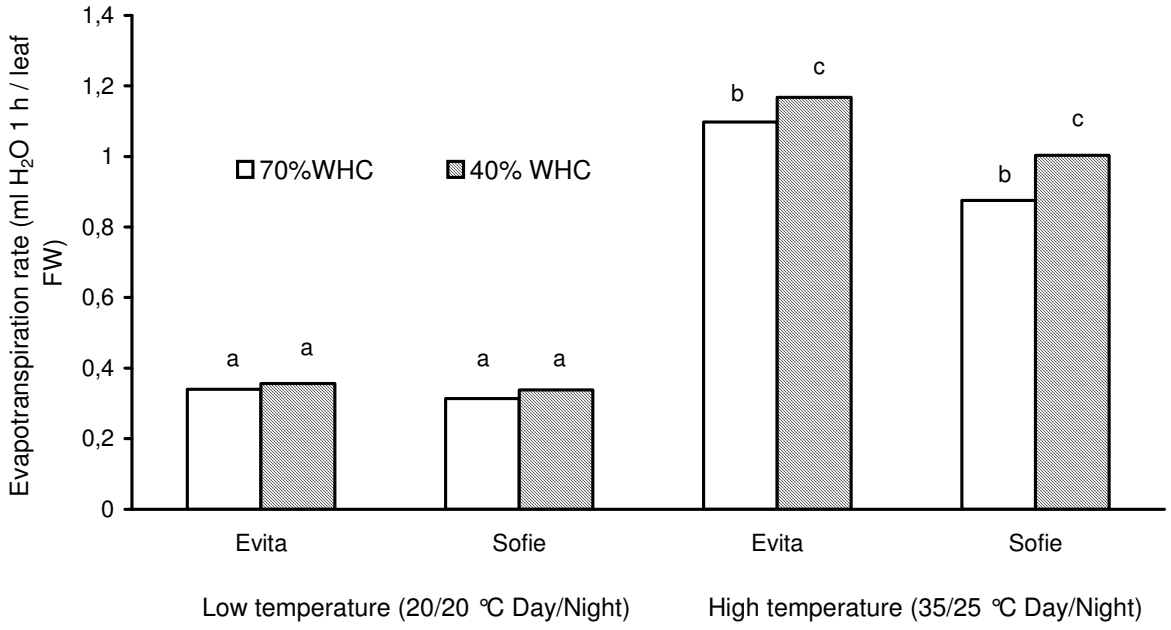

Fig. 43: Effect of drought and heat on the evapotranspiration rate of two sugar beet cultivars grown in soil in growth chambers for 10 weeks

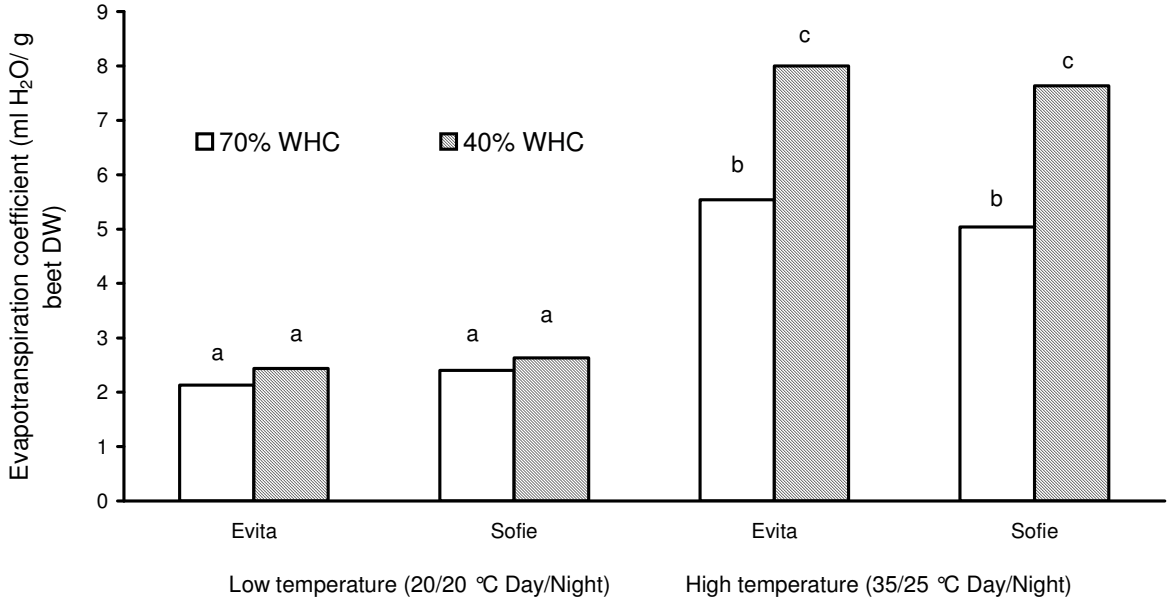

Fig. 44: Effect of drought and heat on the evapotranspiration coefficient of two sugar beet cultivars grown in soil in growth chambers for 10 weeks

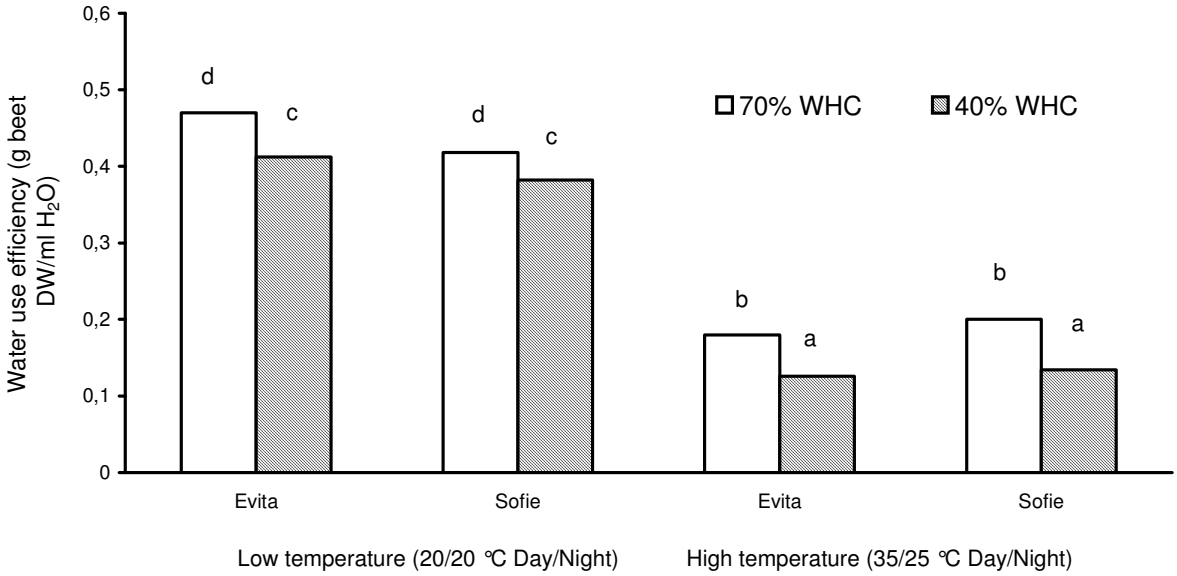

Fig. 45: Effect of drought and heat on the water use efficiency of two sugar beet cultivars grown in soil in growth chambers for 10 weeks

The effect of heat stress significantly decreased Ca^{2+} concentrations of leaves and beets for both cultivars. Leaf and beet Ca^{2+} concentrations decreased significantly under heat stress compared to low temperature for the two water treatments. No significant effect of water stress on Ca^{2+} concentrations of leaves and beets were obtained under low temperature for both cultivars. The same trend was observed for Mg^{2+} concentrations of leaves and beets (Table 17). The concentrations of Cl^- for leaves and beets were not significantly affected by all treatments of drought and heat. Leaf and beet NO_3^- concentrations decreased significantly under heat stress compared for two water treatments for both cultivars. PO_4^{3-} concentrations of leaves were significantly decreased at high temperature only for cultivar Evita. The concentrations of SO_4^{2-} of leaves decreased significantly at high temperature for cultivar Sofie. Beet SO_4^{2-} concentrations decreased significantly at high temperature under two water treatments for cultivar Evita (Table 18).

Table 17: Effect of drought and heat on the cation concentrations of leaves and beets (mg/g DW) of two sugar beet cultivars grown in soil in growth chambers for 10 weeks

Treatments	Leaves															
	Low temperature								High temperature							
	Evita				Sofie				Evita				Sofie			
	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}
70% WHC	26.38 b	2.91 ab	26.59 b	2.54 b	24.80 ab	2.98 b	34.98 b	2.96 b	25.35 b	2.56 ab	14.84 a	1.23 a	23.53 ab	2.32 a	16.09 a	1.34 a
40% WHC	26.24 b	2.80 b	28.72 b	2.85 b	25.88 b	3.10 b	32.20 b	2.82 b	22.27 a	2.33 a	14.21 a	1.16 a	22.21 a	2.57 a	15.71 a	1.21 a
L.S.D 5%	2.61	0.40	3.74	0.69	2.52	0.37	2.96	0.57								
	Beets															
70% WHC	9.184 a	0.31 a	17.46 b	2.26 b	10.28 ab	0.31 a	20.72 b	2.29 b	8.91 a	0.34 a	14.76 a	1.4 a	8.75 a	0.36 a	14.14 a	1.40 a
40% WHC	8.764 a	0.30 a	18.99 b	2.31 b	10.71 b	0.33 a	21.14 b	2.44 b	9.11 a	0.30 a	14.95 a	1.30 a	9.62 ab	0.36 a	13.91 a	1.52 a
L.S.D 5%	1.83	0.09	2.30	0.26	1.12	0.13	2.42	0.51								

Table 18: Effect of drought and heat on the water-soluble anion concentrations of leaves and beets (mg/g DW) of two sugar beet cultivars grown in soil in growth chambers for 10 weeks

Treatments	Leaves															
	Low temperature								High temperature							
	Evita				Sofie				Evita				Sofie			
	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
70% WHC	21.88 a	1.16 b	21.74 b	4.44 a	20.12 a	1.47 b	18.83 a	4.37 b	19.00 a	0.53 a	17.40 a	3.54 a	19.89 a	0.69 a	16.42 a	3.29 a
40% WHC	19.11 a	1.75 b	20.48 b	3.90 a	20.02 a	1.87 b	18.10 a	4.96 b	20.17 a	0.51 a	17.57 a	3.77 a	19.07 a	0.71 a	16.23 a	3.84 a
L.S.D 5%	2.96	0.60	2.84	1.27	2.56	0.58	2.72	0.51								
	Beets															
70% WHC	1.67 a	0.52 b	7.98 a	0.92 b	1.29 a	0.60 b	7.36 a	0.72 a	1.20 a	0.17 a	6.51 a	0.45 a	1.08 a	0.16 a	6.44 a	0.60 a
40% WHC	1.77 a	0.67 b	7.47 a	0.85 b	1.52 a	0.51 b	7.75 a	0.92 a	1.39 a	0.26 a	6.18 a	0.52 a	1.24 a	0.21 a	6.96 a	0.55 a
L.S.D 5%	0.62	0.16	1.94	0.19	0.52	0.11	1.48	0.48								

A significant effect of high temperature was observed on beet α-amino-N concentrations for both cultivars. Nevertheless, no significant effect of drought was detected on α-amino-N concentrations under both temperature treatments (Fig. 46).

Sucrose and glucose concentrations of beets increased significantly under high temperature for two water treatments for both cultivars (Fig. 47 and 48). The effect of neither drought nor temperature was found to be significant on fructose concentrations for both cultivars (Fig. 49). Sucrose, glucose and fructose concentrations were not significantly affected by drought under low temperature. Sucrose concentrations (% FW) increased significantly only for cultivar Evita at 70% WHC coupled with high temperature (Fig. 50). In contrast to sucrose concentrations, sugar and white sugar yields decreased significantly in all drought and heat treatments for both cultivars (Fig. 51 and 52).

The analysis of variance showed that the effects of drought, heat and genotype on leaf and beet fresh weights and beet dry weight were significant. However, leaf dry weight was significantly affected only by heat and drought (Table 19). High temperature was significantly affected the K^+ of beet and Ca^{2+} and Mg^{2+} concentrations of leaves and beets, whereas the effect of drought was not significant. The effect of genotype was significant on K^+ concentrations of leaves and beets and Mg^{2+} concentrations of beets (Table 19). Water consumption was significantly affected by drought and heat (Table 20). A significant effect of heat was observed on the sugar concentrations. Sugar and white sugar yields were significantly affected by drought, heat and genotype (Table 20).

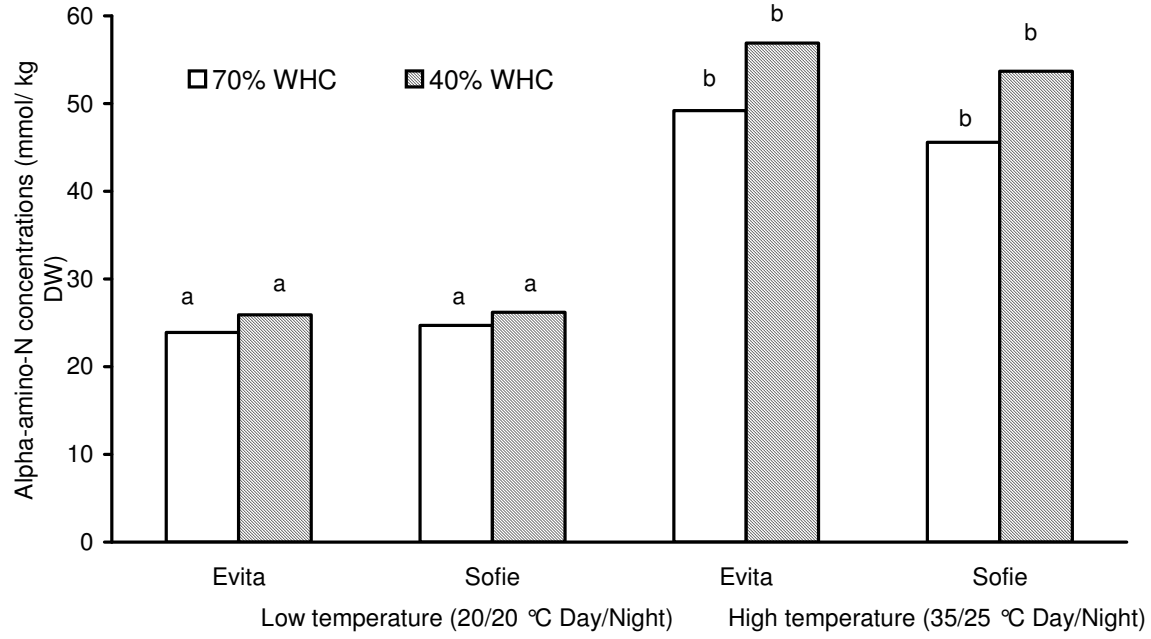

Fig. 46: Effect of drought and heat on the alpha-amino-N concentrations of beets of two sugar beet cultivars grown in growth chambers for 10 weeks

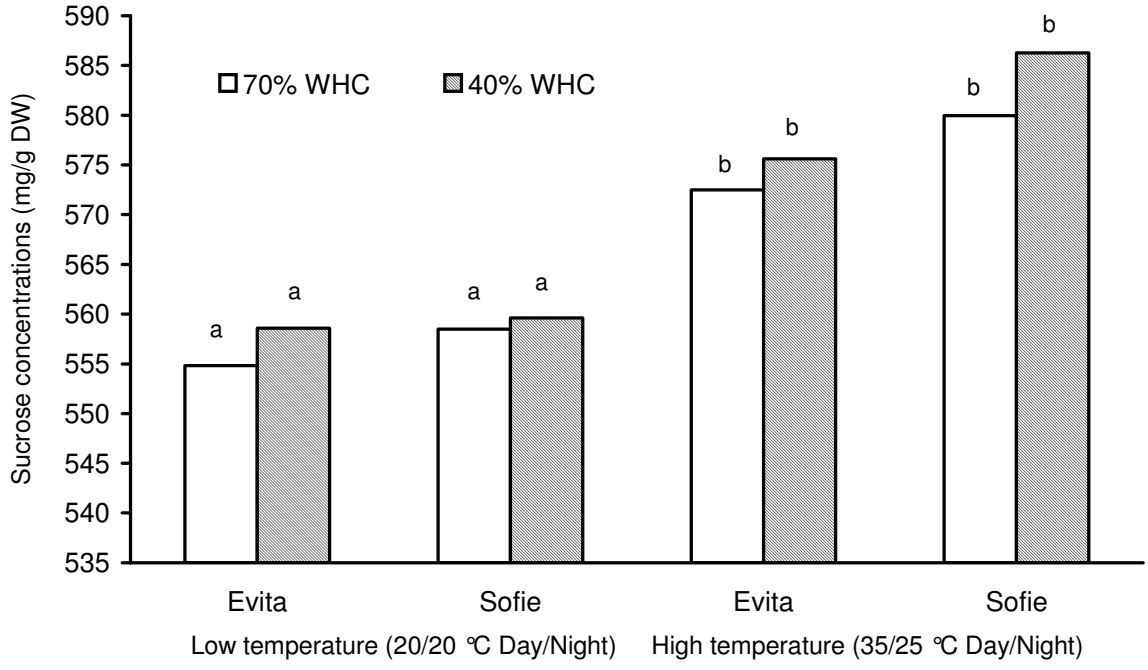

Fig. 47: Effect of drought and heat on the sucrose concentrations of beets of two sugar beet cultivars grown in growth chambers for 10 weeks

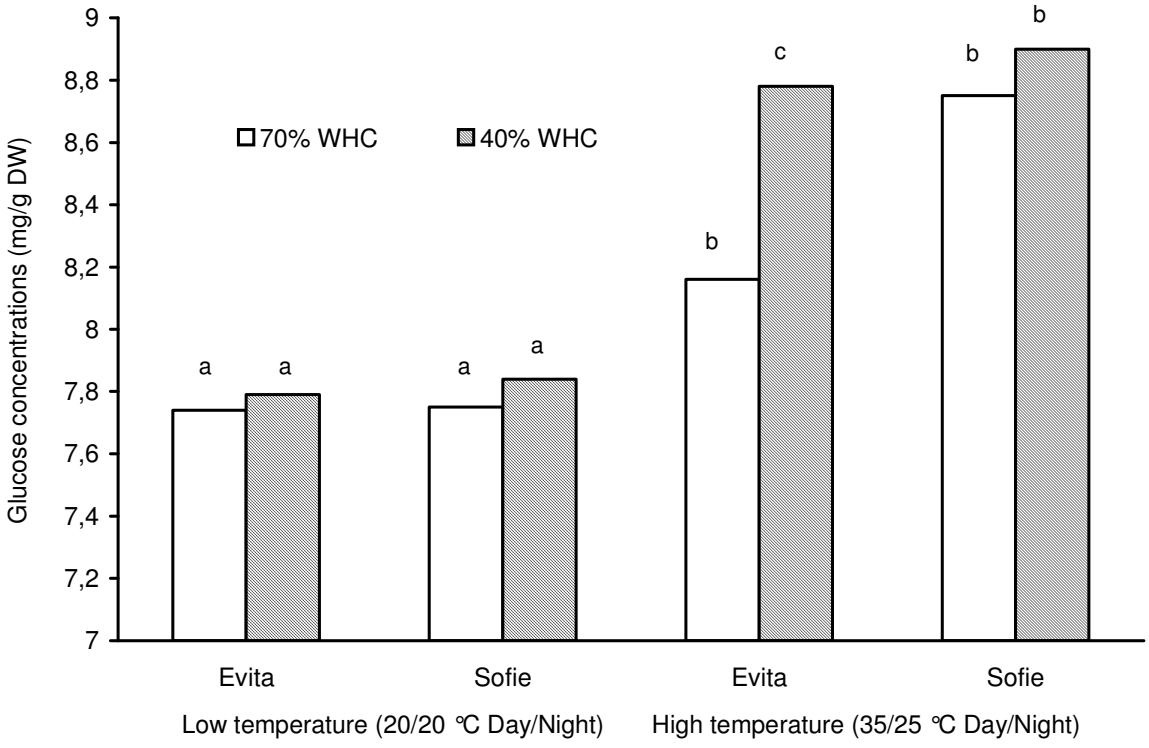

Fig. 50: Effect of drought and heat on the glucose concentrations of beets of two sugar beet cultivars grown in growth chambers for 10 weeks

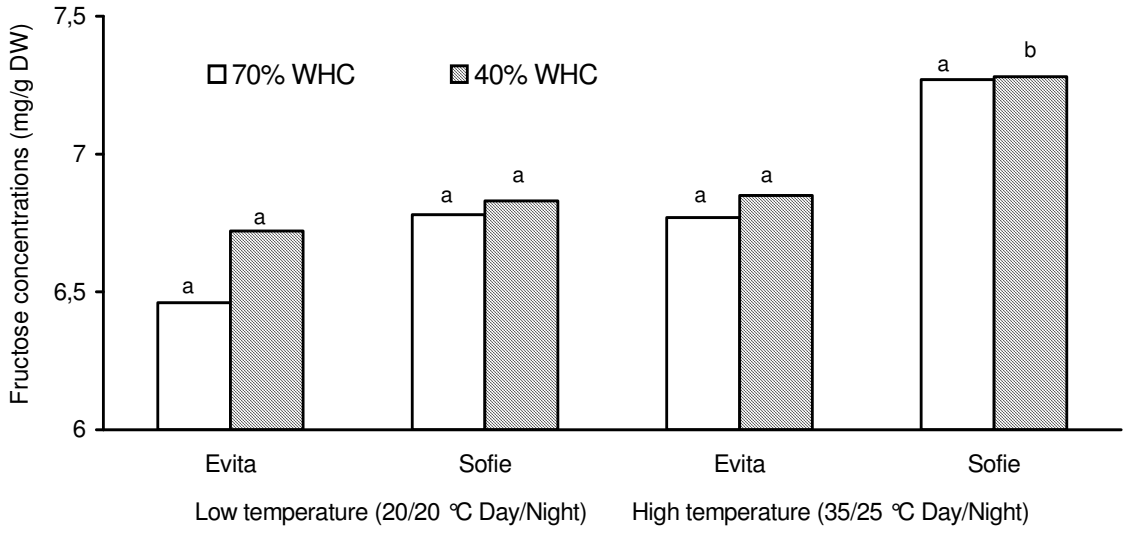

Fig. 49: Effect of drought and heat on the fructose concentrations of beets of two sugar beet cultivars grown in growth chambers for 10 weeks

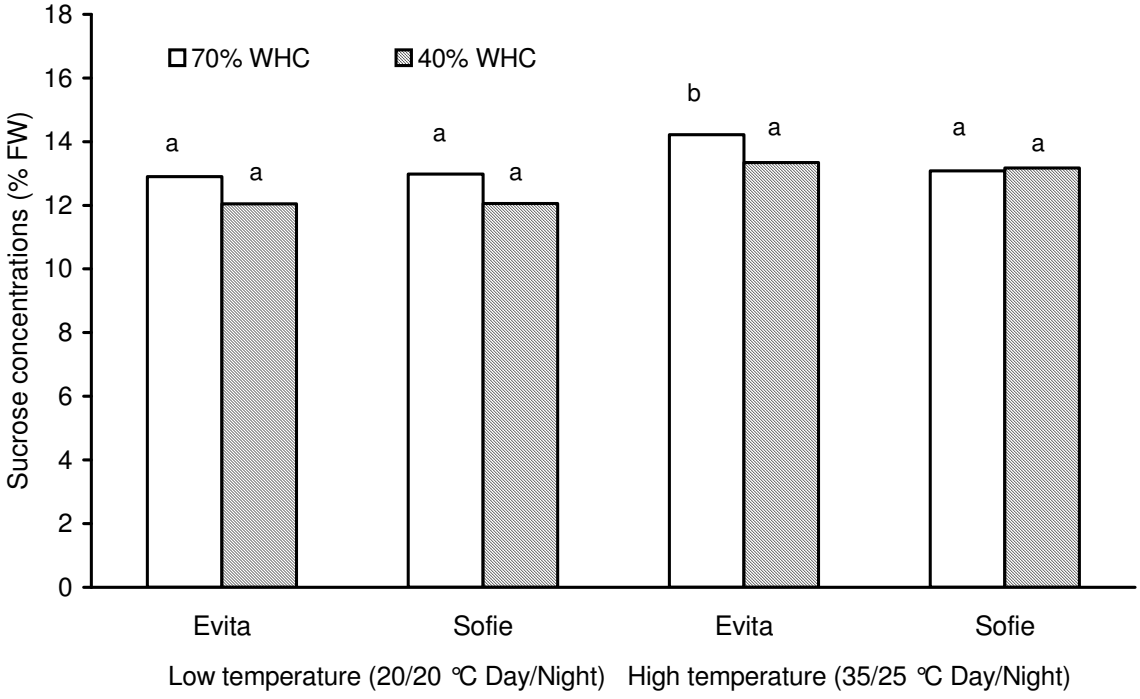

Fig. 50: Effect of drought and heat on the sucrose concentrations of beets of two sugar beet cultivars grown in growth chambers for 10 weeks

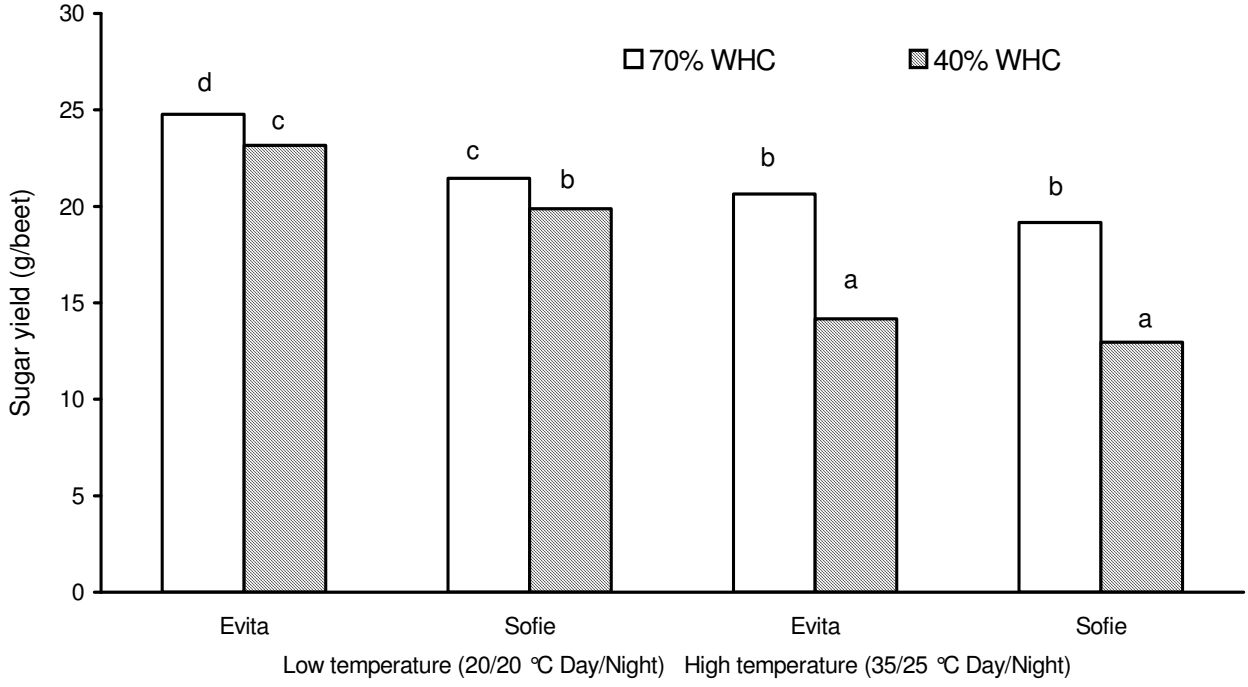

Fig. 51: Effect of drought and heat on the sugar yield of beets of two sugar beet cultivars grown in growth chambers for 10 weeks

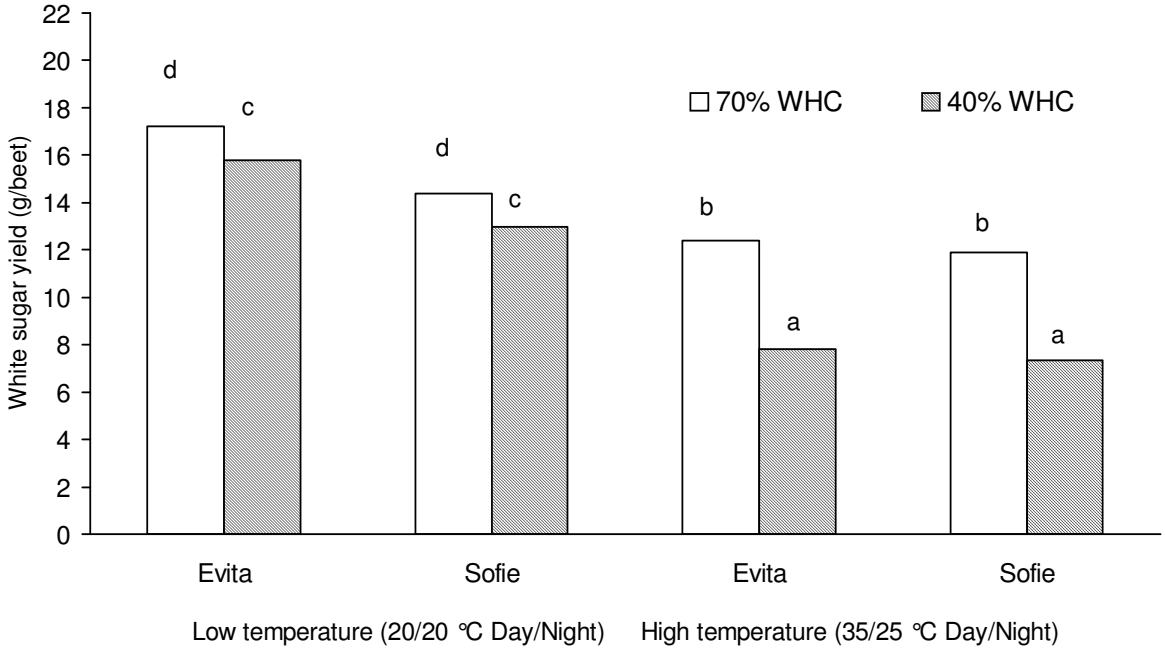

Fig. 52: Effect of drought and heat on the white sugar yield of two sugar beet cultivars grown in growth chambers for 10 weeks

Table 19: Analysis of variance of effect of drought and heat on plant growth and cation concentrations of two sugar beet genotypes grown in soil in growth chambers for 10 weeks

Source	Leaves				Beets			
	fresh weight		dry weight		fresh weight		dry weight	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Genotype	332.85	4.15*	24.78	4.0^{NS}	917.5	11.27*	222.0	21.27**
Temperature	138804	1728.6**	206.4	33.6**	35276.6	433.3**	1526.3	146.22**
Water stress	1682.7	20.96**	34.19	5.57*	8032.6	98.65**	611.97	58.63**
Error	80.3		6.14		81.42		10.44	
	Cations							
	K^+		Na^+		K^+		Na^+	
Genotype	9.1	2.1^{NS}	0.07	0.8^{NS}	7.16	7.7*	0.006	1.3^{NS}
Temperature	9.1	2.1^{NS}	0.07	0.8^{NS}	4.06	4.3*	0.0073	1.5^{NS}
Water stress	61.7	14.3**	2.6	27.0**	0.71	0.76^{NS}	0.0001	0.02^{NS}
Error	7.5	1.7^{NS}	0.0001	0.001^{NS}	0.94		0.005	
	Ca^{2+}		Mg^{2+}		Ca^{2+}		Mg^{2+}	
Genotype	133.3	13.6**	9.0	1.9^{NS}	0.2	3.4^{NS}	0.21	5.4*
Temperature	2374.5	242.9**	264.4	54.4**	24.3	422.8**	9.31	242.5**
Water stress	1.7	0.2^{NS}	2.4	0.5^{NS}	0.001	0.01^{NS}	0.001	0.03^{NS}
Error	9.8		4.9		0.06		0.04	

Table 20: Analysis of variance of effect of drought and heat on sugar concentrations, sugar yield, white sugar yield and water relations of two sugar beet genotypes grown in soil in growth chambers for 10 weeks

Source	Sucrose		Glucose		Fructose		Sucrose % FW		Sugar yield	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Genotype	333.51	3.94 ^{NS}	0.37	4.25*	1.04	8.72*	4.15	3.32 ^{NS}	52.9	17.28**
Temperature	4299.4	50.83**	7.56	87.6**	1.07	8.92*	9.22	7.38*	312.48	102.1**
Water stress	124.26	1.47 ^{NS}	0.51	5.94*	0.14	1.17 ^{NS}	0.94	0.75 ^{NS}	156.82	51.23**
Error	84.59		0.086		0.12		1.25		3.06	
	White sugar yield		Evapotranspiration		Evapotranspiration rate		Evapotranspiration coefficient		Water use efficiency	
Genotype	46.088	14.52**	3396.8	23.2 ^{NS}	0.84	12.3 ^{NS}	15.74	7.52 ^{NS}	0.002	11.4 ^{NS}
Temperature	522.22	164.5**	91144	622.1**	5.86	622.39*	206.99	306.4**	0.813	1019.5**
Water stress	184.34	58.07**	52.98	0.24 ^{NS}	0.043	4.53*	23.35	34.56**	0.035	43.81**
Error	3.17		146.5		0.009		0.68		0.001	

4.2 Nutrient solution experiments

4.2.1 Effects of K^+ substitution by Na^+ on the growth of two sugar beet cultivars grown under natural conditions

In this experiment 1/4, 1/2 and full strength of nutrient solution, which included 4 mM KCl were used for all plants. After 3 weeks of growth in the full nutrient solution, nine treatments were established.

A strong effect of K^+ substitution by Na^+ on the growth of leaves and beets was noticed (Photo 2).

Fresh weight of leaves increased significantly at 0.1 mM K^+ and 0.1 mM K^+ + 0.1 mM Na^+ supply compared to free of K^+ and Na^+ treatment for both cultivars. Leaf fresh weight was also significantly increased in all treatments of K^+ substitution by Na^+ compared to 4.0 mM K^+ for both cultivars (Fig. 53). Leaf dry weight increased significantly at 0.1 mM K^+ and 0.1 mM K^+ + 0.1 mM Na^+ supply compared to free of K^+ + Na^+ treatment for cultivar Evita only. At 25 and 50% K^+ substitution, leaf dry weight was not significantly affected compared to the 4.0 mM K^+ treatment for the two cultivars. However, leaf dry weight increased significantly at 75% K^+ substitution compared to the 4.0 mM K^+ treatment for both cultivars (Fig. 54). Beet fresh weight increased significantly at 0.1 mM K^+ and 0.1 mM K^+ + 0.1 mM Na^+ supply compared to free of K^+ and Na^+ treatment for both cultivars. Fresh weight of beets increased significantly in the treatments with 25, 50 and 75% K^+ substitution compared to 4.0 mM K^+ treatment. At 4.0 mM Na^+ treatment the beet fresh yield was reduced significantly compared to the 4.0 mM K^+ treatment (Fig. 55). Dry weight of beets increased significantly at 0.1 mM K^+ + 0.1 mM Na^+ supply compared to free of K^+ + Na^+ treatment for both cultivars. At the treatments with 25, 50 and 75% K^+ substitution, beet dry weight was not significantly affected, whereas the reduction of beet dry weight was significant at 4.0 mM Na^+ treatment compared to 4.0 mM K^+ treatment (Fig. 56).

0.0 mM KCl + 0.0 mM NaCl	0.1 mM KCl + 0.0 mM NaCl	0.0 mM KCl + 0.1 mM NaCl	0.1 mM KCl + 0.1 mM NaCl

4.0 mM KCl + 0.0 mM NaCl	3.0 mM KCl + 1.0 mM NaCl	2.0 mM KCl + 2.0 mM NaCl	1.0 mM KCl + 3.0 mM NaCl	0.0 mM KCl + 4.0 mM NaCl

Photo 2 Effect of K^+ substitution by Na^+ on the growth of sugar beet plants (cv. Evita) grown in nutrient solution under natural conditions for 10 weeks

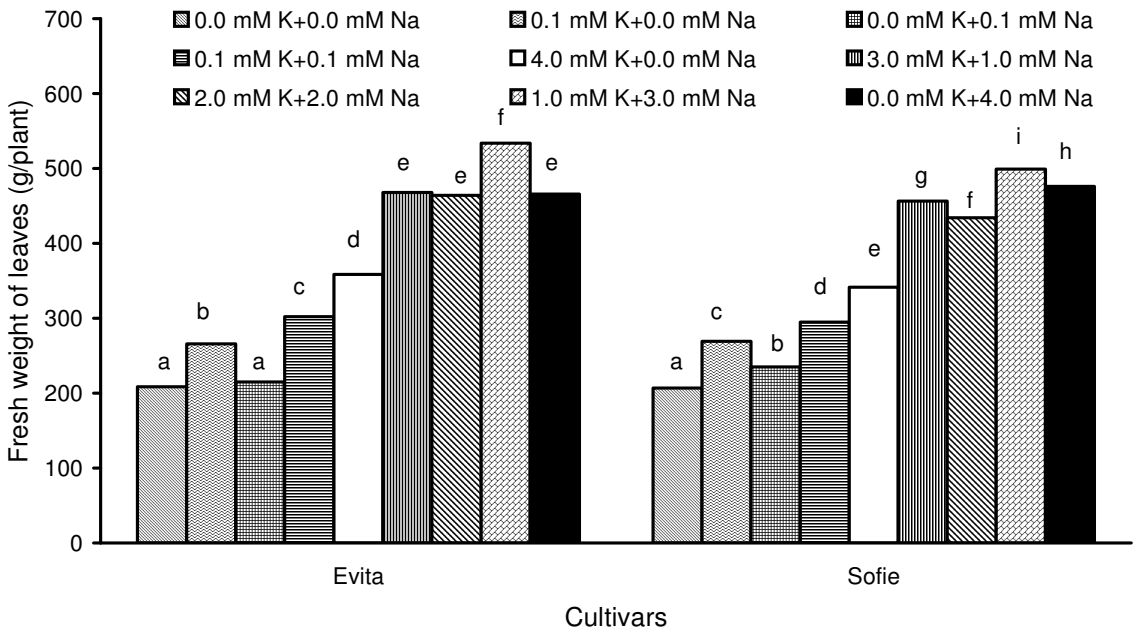

Fig. 53: Effect of K^+ substitution by Na^+ on the fresh weight of leaves of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

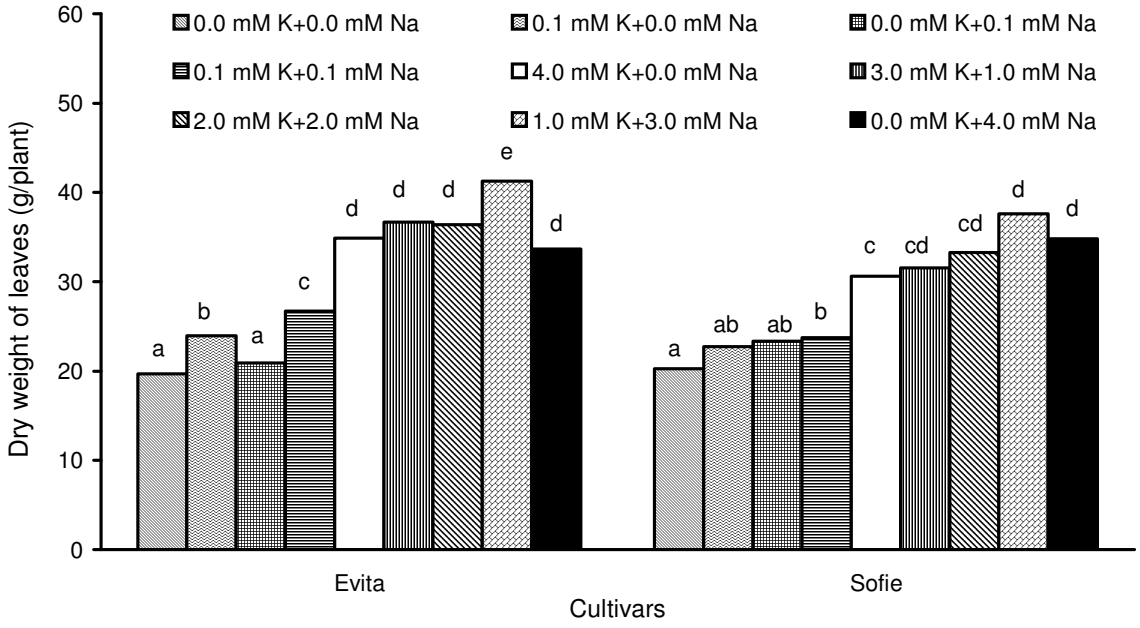

Fig. 54: Effect of K^+ substitution by Na^+ on the dry weight of leaves of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

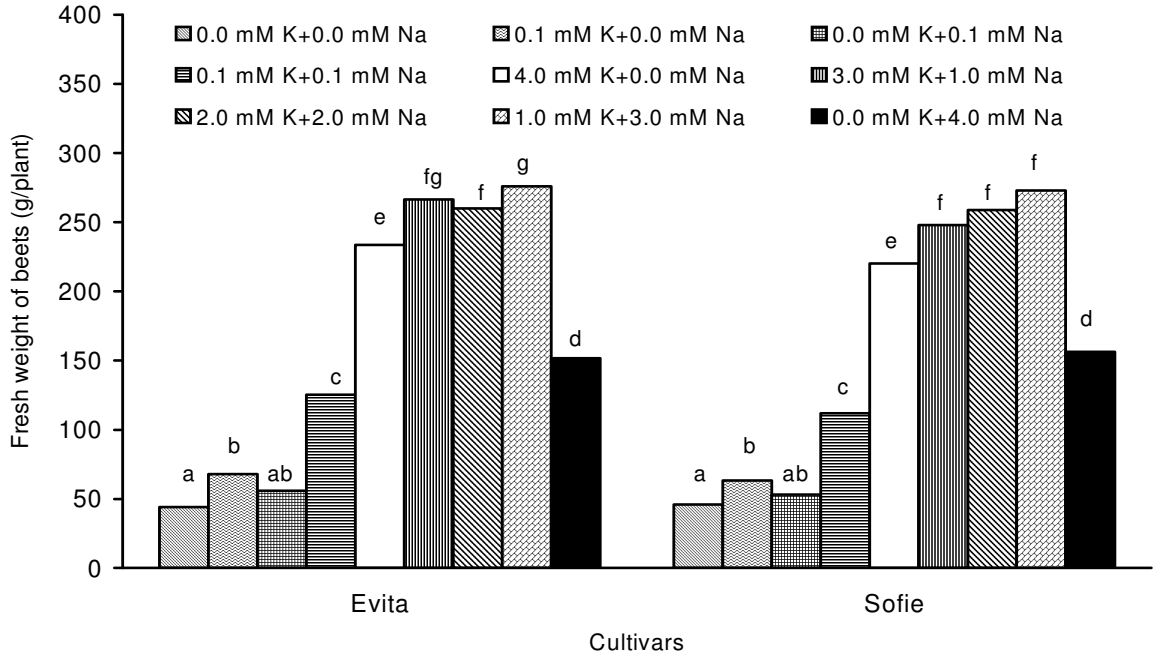

Fig. 55: Effect of K^+ substitution by Na^+ on the fresh weight of beets of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

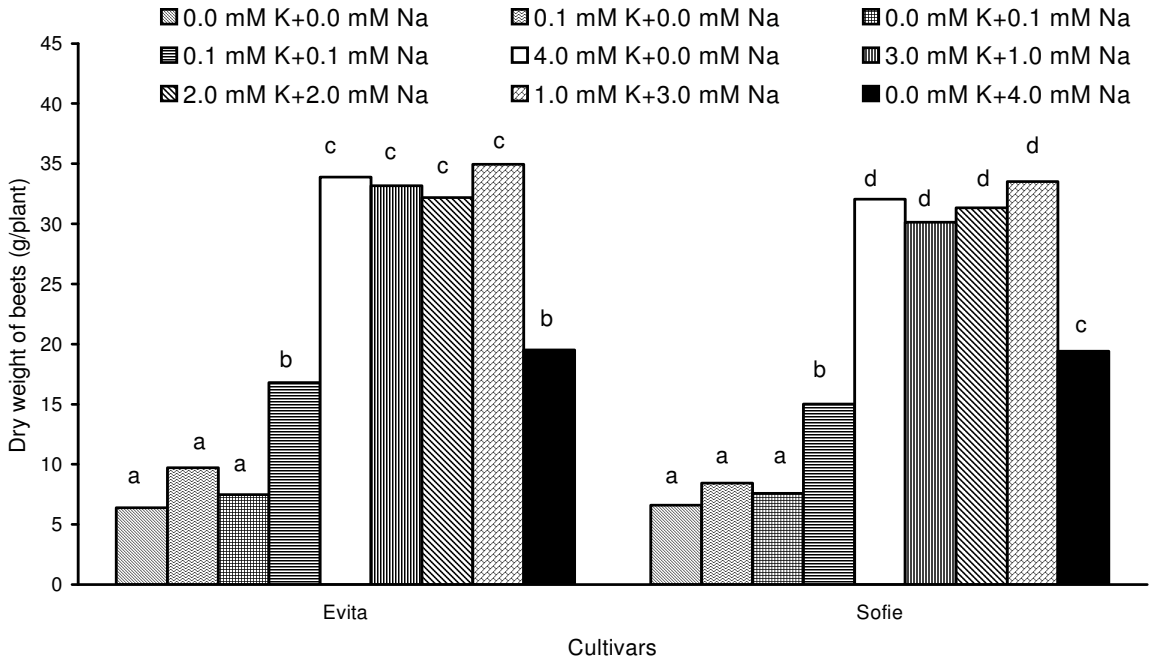

Fig. 56: Effect of K^+ substitution by Na^+ on the dry weight of beets of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

Transpiration (T) increased significantly with increasing K^+ substitution compared to 4.0 mM K^+ treatment. However, no significant effect on transpiration was obtained in the treatments with low K^+ or Na^+ supply compared to free of K^+ and Na^+ treatment for the two cultivars (Fig. 57). Transpiration rate (TR) and transpiration coefficient (TC) increased significantly at 0.1 mM K^+, 0.1 mM Na^+, 0.1 mM K^+ + 0.1 mM Na^+ and 4.0 mM Na^+ supply compared to 4.0 mM K^+ treatment for both cultivars. However the two parameters were not significantly affected in the treatments with 25, 50 and 75% K^+ substitution compared to 4.0 mM K^+ (Fig. 58 and 59). Water use efficiency (WUE) of beets decreased significantly with increasing K^+ substitution compared to 4.0 mM K^+ treatment for both cultivars (Fig. 60).

Leaf and beet K^+ concentrations decreased significantly in the treatments with 25, 50, 75 and 100% K^+ substitution compared to the 4.0 mM K^+ treatment. Leaf and beet Na^+ concentrations increased significantly in the 0.1 mM Na^+ and 0.1 mM K + 0.1 mM Na^+ treatments and in the treatments with 25, 50, 75 and 100% K^+ substitution for two cultivars, compared to the free K^+ and Na^+ or the 4.0 mM K^+ treatment (Table 21). In contrast to Na^+ concentrations, Ca^{2+} concentrations of leaves decreased significantly at 0.1 mM K^+, 0.1 mM Na^+ and 0.1 mM K^+ + 0.1 mM Na^+ treatments compared to the free K^+ + Na^+ treatment for both cultivars. In the treatments with 25, 50, 75 and 100% K^+ substitution, Ca^{2+} concentrations were also significantly decreased compared to the 4.0 mM K^+ treatment. Beet Ca^{2+} concentrations were decreased significantly at low K^+ + Na^+ treatment compared to free K^+ + Na^+ supply only for cultivar Sofie. Also, Ca^{2+} concentrations of beets decreased significantly at 4.0 mM Na^+ treatment compared to 4.0 mM K^+ for both cultivars. Leaf Mg^{2+} concentrations decreased significantly with low K^+ + Na^+ supply compared to free K^+ + Na^+ treatment for both cultivars. Similarly, the concentration decreased significantly in the treatment with 75 and 100% K^+ substitution compared to the 4.0 mM K^+ treatment. The Mg^{2+} concentrations of beets were not significantly affected, except at low K^+ + Na^+ supply for cultivar Sofie compared to free K^+ + Na^+ supply (Table 22).

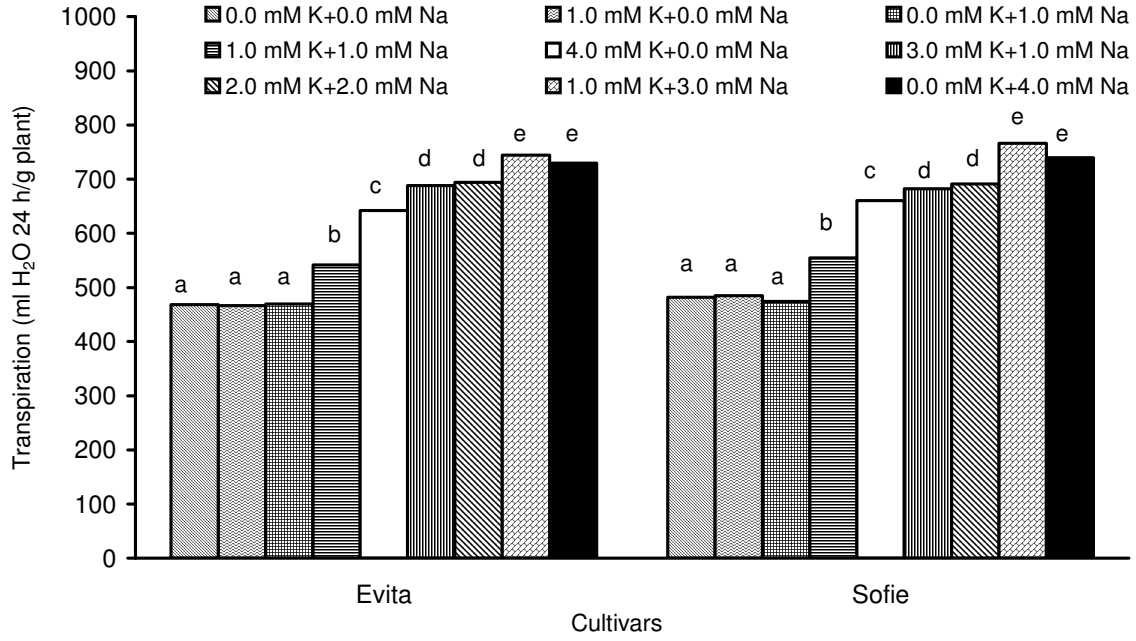

Fig. 57: Effect of K^+ substitution by Na^+ on the transpiration of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

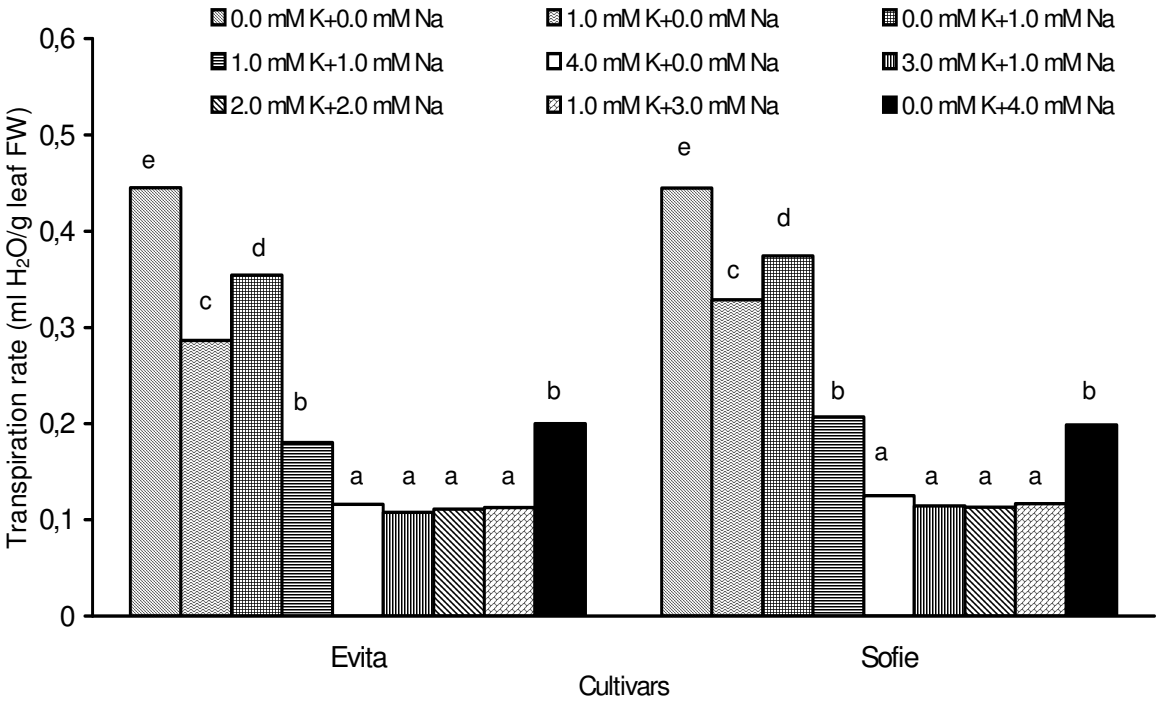

Fig. 58: Effect of K^+ substitution by Na^+ on the transpiration rate of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

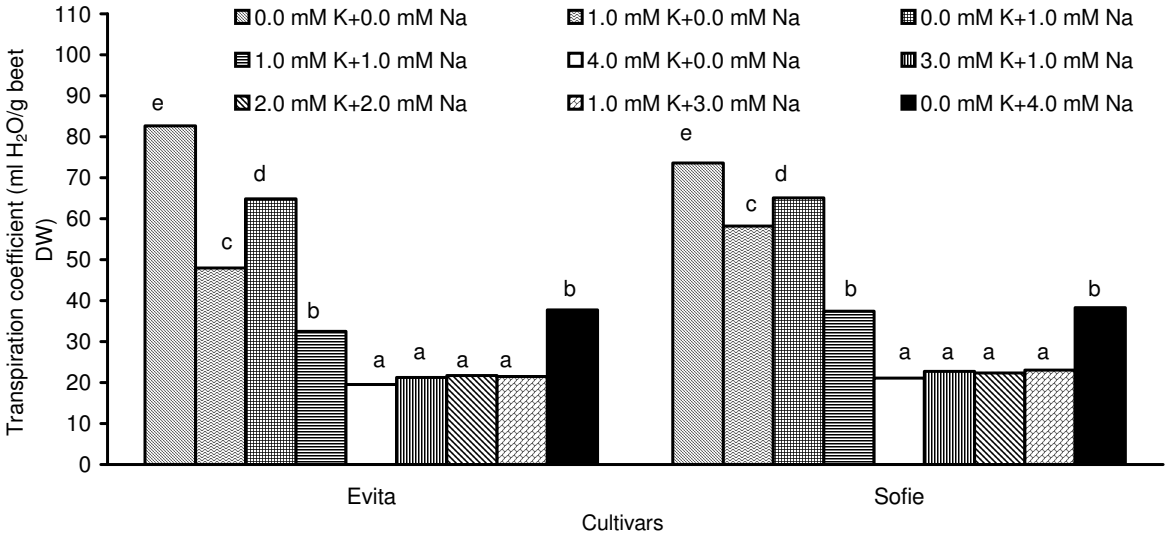

Fig. 59: Effect of K^+ substitution by Na^+ on the transpiration coefficient of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

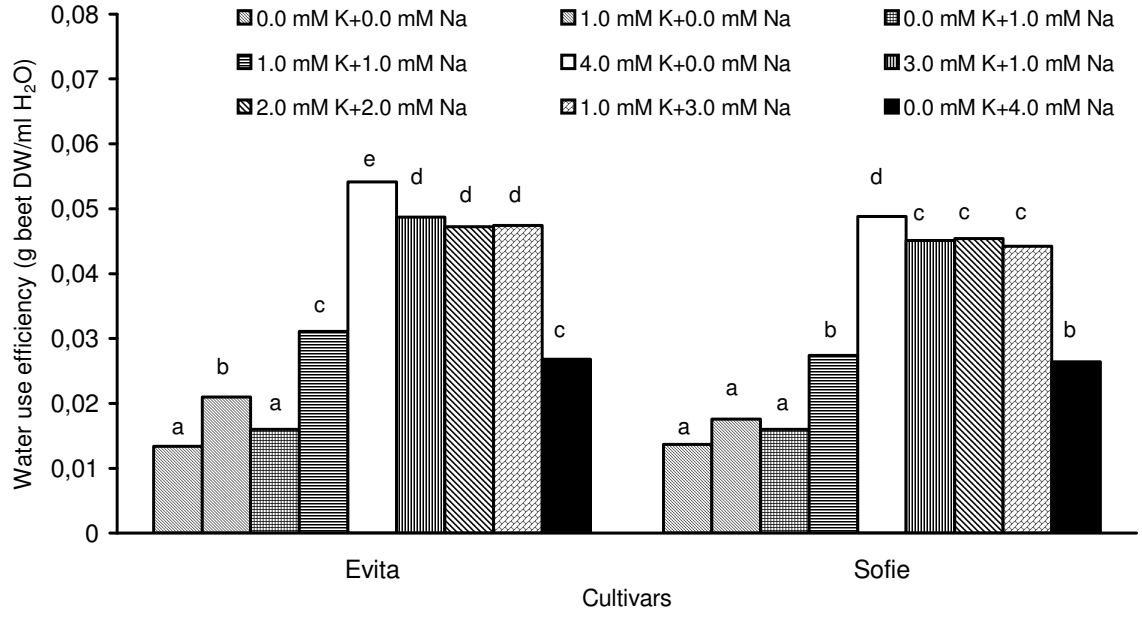

Fig. 60: Effect of K^+ substitution by Na^+ on the water use efficiency of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

Table 21: Effect of K^+ substitution by Na^+ on the cation concentrations of leaves (mg/g DW) of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

Treatments K^+/Na^+ (mM/L)	Evita				Sofie			
	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}
0.0 K + 0.0 Na	15.5 b	0.83 a	19.1 g	17.3 d	15.1 a	0.87 a	19.5 f	18.3 ef
0.1 K + 0.0 Na	22.7 c	0.88 a	17.6 e	18.4 d	22.0 b	0.79 a	18.7 f	19.1 f
0.0 K + 0.1 Na	11.6 a	8.01 b	18.0 eg	18.4 d	11.4 a	7.21 b	15.5 d	17.2 e
0.1 K + 0.1 Na	13.3 a	6.16 b	14.8 d	15.8 c	14.1 a	5.94 b	17.2 e	15.0 d
4.0 K + 0.0 Na	96.8 g	0.67 a	9.15 c	11.5 b	92.0 f	0.67 a	9.28 c	12.0 c
3.0 K + 1.0 Na	79.7 f	13.9 c	7.30 b	10.9 b	78.6 e	13.4 c	7.46 b	10.6 bc
2.0 K + 2.0 Na	71.6 e	23.3 d	8.10 bc	10.7 b	72.1 d	22.6 d	7.86 b	10.5 bc
1.0 K + 3.0 Na	41.6 d	41.1 e	6.39 ab	9.4 a	44.5 c	39.0 e	6.72 b	9.98 b
0.0 K + 4.0 Na	10.4 a	62.6 f	5.4 a	8.5 a	10.7 a	65.3 f	5.07 a	8.19 a
L.S.D 5%	4.74	2.11	1.44	1.47				

Critical values of cations according to Bergmann (1992):
35- 60 mg K^+/g DW
7-20 mg Ca^{2+}/g DW
3-7 mg Mg^{2+}/g DW

Table 22: Effect of K^+ substitution by Na^+ on the cation concentrations of beets (mg/g DW) of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

Treatments K^+/Na^+ (mM/L)	Evita				Sofie			
	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}
0.0 K + 0.0 Na	11.9 c	0.45 a	1.50 c	1.20 ab	12.4 c	0.37 a	1.52 d	1.15 a
0.1 K + 0.0 Na	12.7 c	0.33 a	1.47 c	1.16 a	13.3 c	0.36 a	1.48 d	1.26 ab
0.0 K + 0.1 Na	8.58 b	4.12 d	1.44 c	1.23 ab	9.96 b	3.16 d	1.53 d	1.29 ab
0.1 K + 0.1 Na	13.1 c	1.42 b	1.44 c	1.20 ab	12.1 c	1.21 b	1.27 c	1.17 a
4.0 K + 0.0 Na	33.5 f	0.29 a	1.14 b	1.22 ab	34.6 g	0.27 a	1.08 b	1.32 b
3.0 K + 1.0 Na	31.5 e	1.32 b	1.13 b	1.21 ab	32.1 f	1.25 b	1.11 b	1.39 b
2.0 K + 2.0 Na	30.2 e	2.36 c	1.06 b	1.33 b	30.5 e	2.51 c	1.14 c	1.33 b
1.0 K + 3.0 Na	21.5 d	8.47 e	1.10 b	1.24 ab	21.2 d	8.52 e	0.97 b	1.23 ab
0.0 K + 4.0 Na	6.00 a	16.4 f	0.81 a	1.24 ab	6.41 a	16.4 f	0.80 a	1.25 ab
L.S.D 5%	1.27	0.657	0.16	0.145				

Beet α-amino-N concentrations were significantly increased in all treatments of K^+ + Na^+ free, low K^+ , low Na^+, and low K^+ + Na^+ treatments compared to 4.0 mM K^+ treatment for both cultivars. Also, α- amino-N concentrations was significantly increased in all treatments of K^+ substitution for cultivar Evita, and at 75 and 100% K^+ substitution for cultivar Sofie compared to 4.0 mM K^+ treatment (Fig. 61).

The sucrose concentrations (mg/g DW) of beets decreased significantly at low Na^+ supply compared to the K^+ and Na^+ free treatment for both cultivars. Also, sucrose concentrations were decreased by increasing K+ substitution compared to 4 mM KCl treatment for both cultivars (Fig. 62). Glucose concentrations decreased significantly at low Na^+ or K^+ supply compared to 4.0 mM K^+ treatment (Fig. 63), whereas fructose concentrations reduced significantly in all treatments of K^+ substitution for both cultivars (Fig. 64). The same trend was observed for the sucrose concentrations (% FW) (Fig. 65). Sugar yield and white sugar yield increased significantly at 0.1 mM K^+ + 0.1 mM Na^+ compared to the free of K^+ and Na^+ treatment, whereas sugar yield and white reduced significantly at 100% K^+ substitution compared to the 4.0 mM K^+ treatment for both cultivars. These two parameters, however, were not significantly affected at 25, 50 and 75% K^+ substitution compared to the 4.0 mM K^+ treatment (Fig. 66 and 67). It is evident that the sugar and white sugar yields were higher in plants with high K^+ supply compared to low K^+ supply plants.

The results of the analysis of variance showed that the substitution K^+ by Na^+ treatments exhibited a strong effect on the parameters measured in this study and that the differences between the cultivars are not statistically significant (Table 23 and 24).

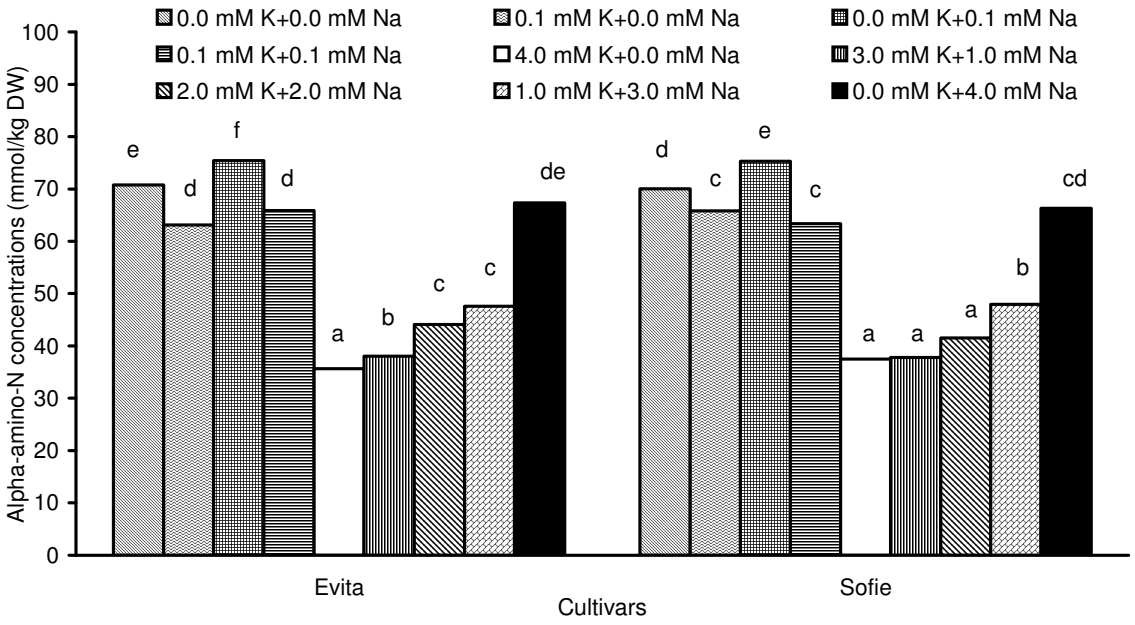

Fig. 61: Effect of K^+ substitution by Na^+ on the alpha amino-N concentrations of beets of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

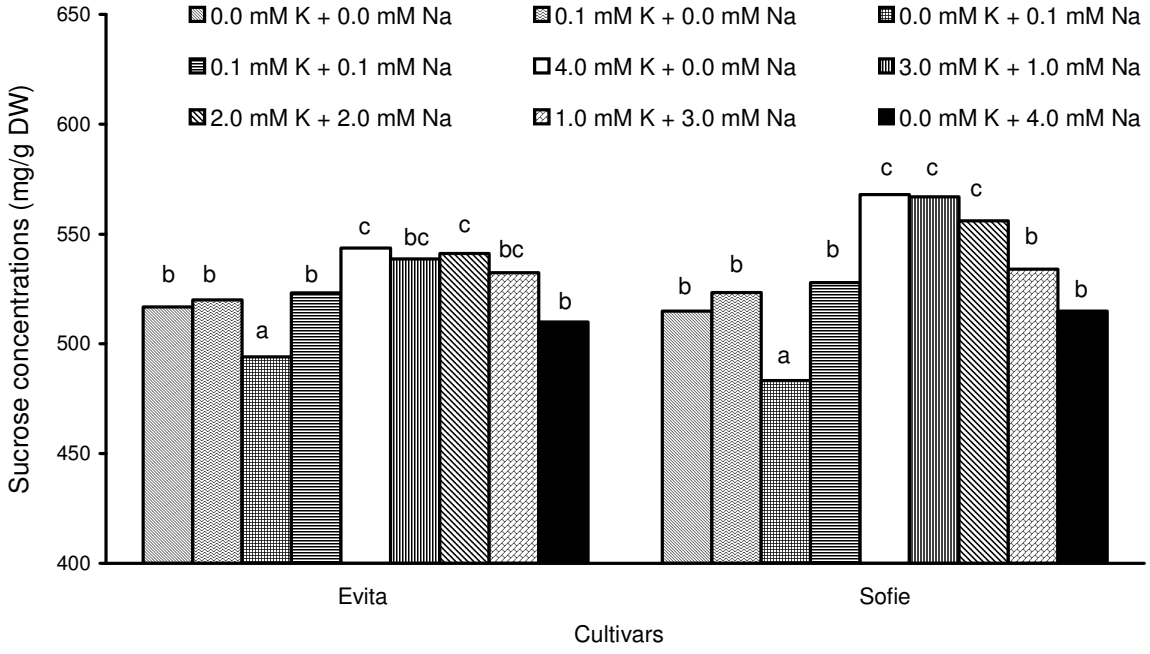

Fig. 62: Effect of K^+ substitution by Na^+ on the sucrose concentrations of beets of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

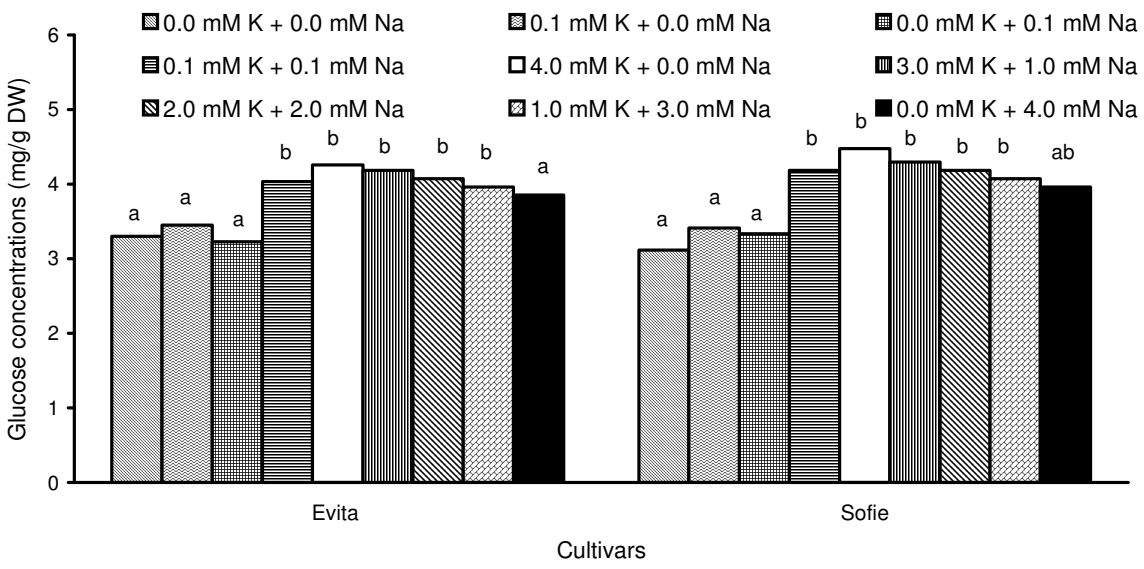

Fig. 63: Effect of K^+ substitution by Na^+ on the glucose concentrations of beets of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

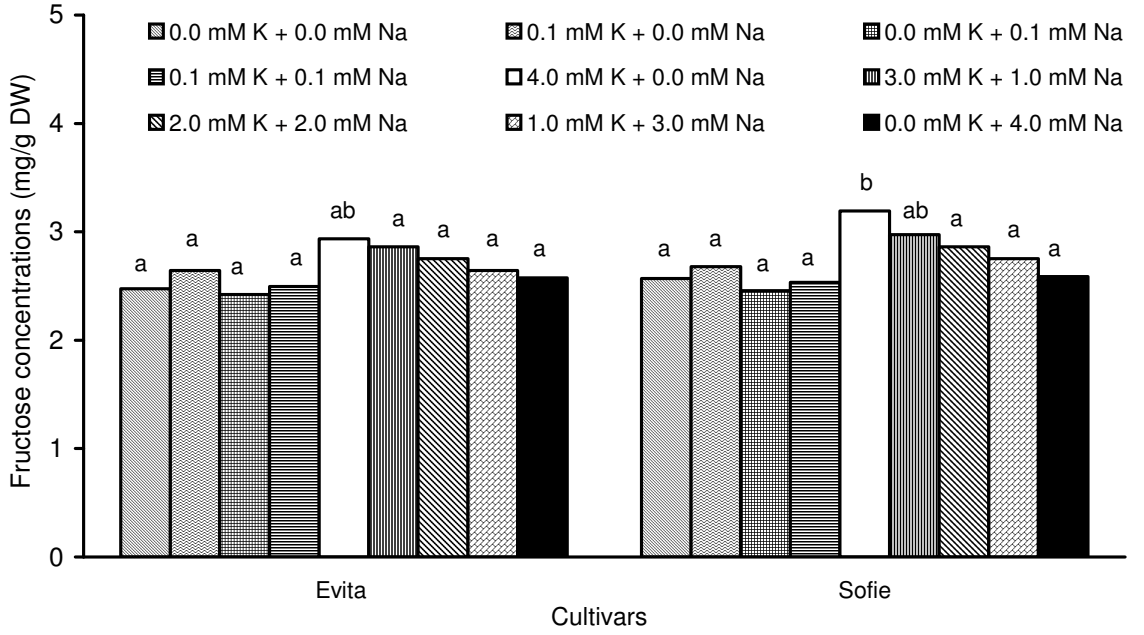

Fig. 64: Effect of K^+ substitution by Na^+ on the fructose concentrations of beets of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

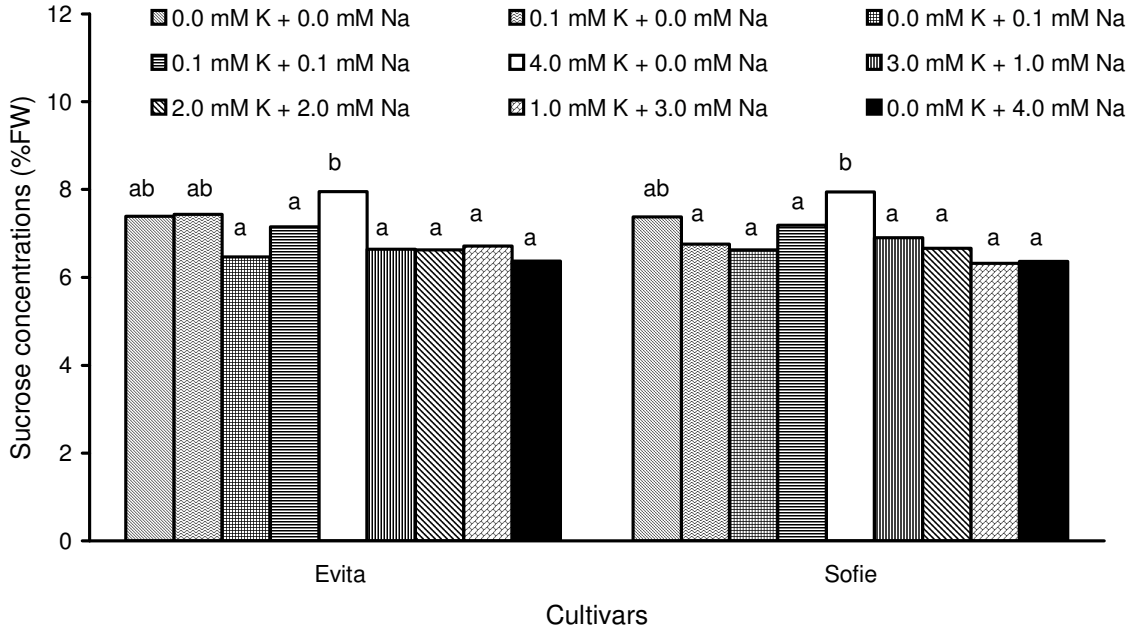

Fig. 65: Effect of K^+ substitution by Na^+ on the sucrose concentrations of beets of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

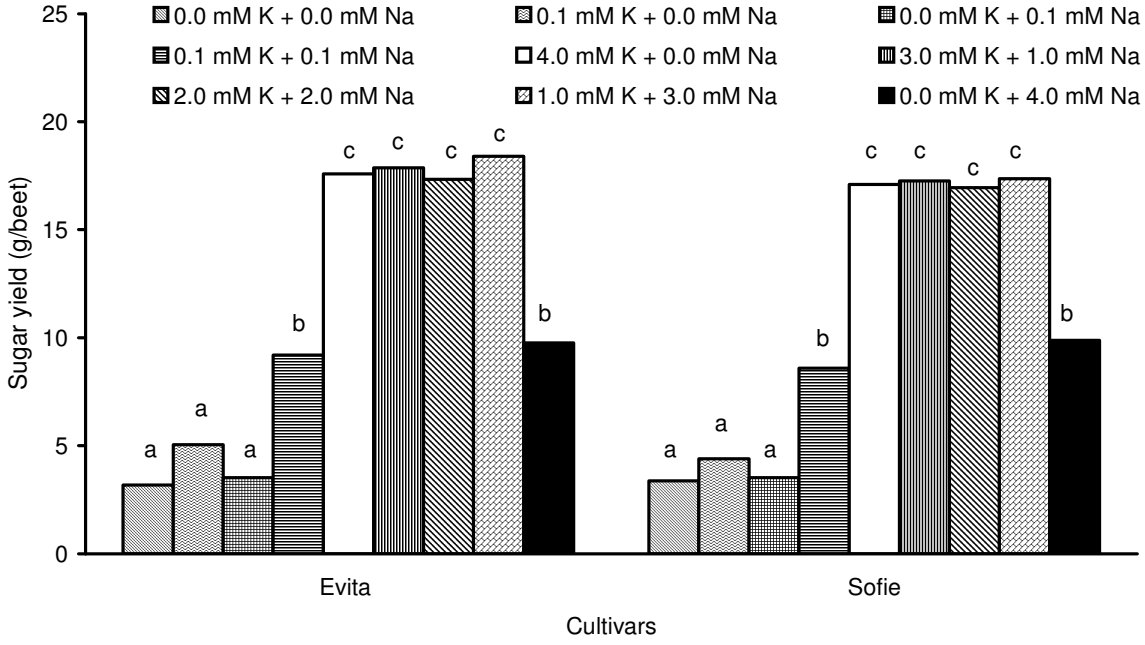

Fig. 66: Effect of K^+ substitution by Na^+ on the sugar yield of beets of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

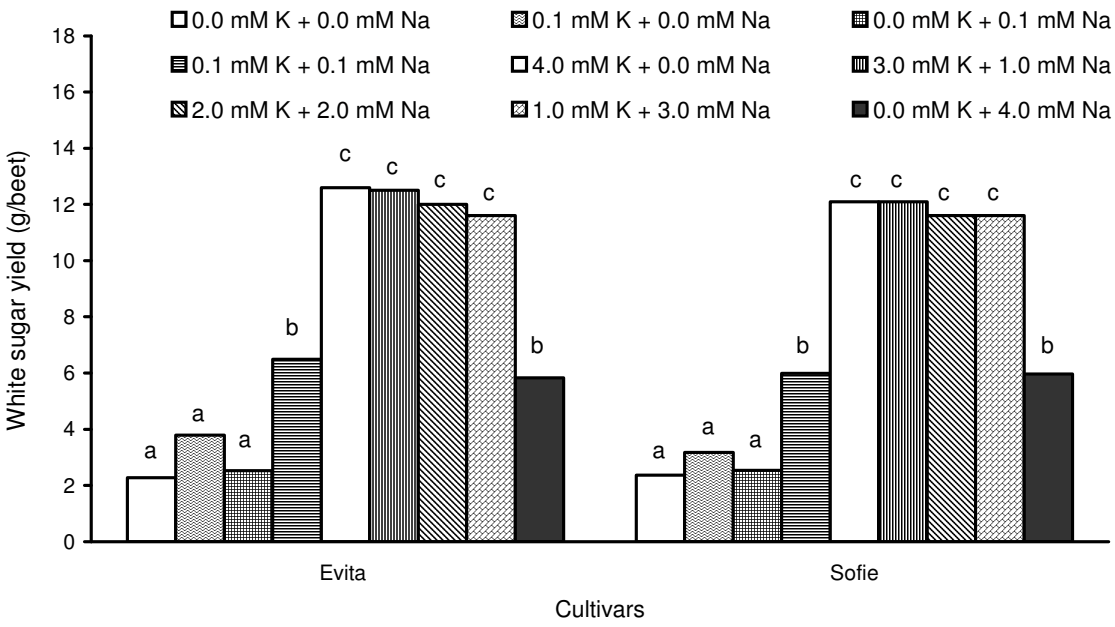

Fig. 67: Effect of K^+ substitution by Na^+ on white sugar yield of beet of two sugar beet cultivars grown in nutrient solution under natural conditions for 10 weeks

Table 23: Analysis of variance of effect of K^+ substitution by Na^+ on plant growth, cation concentrations and water relations of two sugar beet cultivars grown in nutrient solution in growth chamber for 10 weeks

Source	Leaves				Beets			
	fresh weight		dry weight		fresh weight		dry weight	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Genotype	1569.5	4.5^{*}	88.0	8.6^{*}	852.7	4.5^{*}	33.5	3.5^{NS}
Treatment	163402	464.2^{*}	575.3	56.0^{**}	107854	568.0^{**}	1664.8	174.7^{**}
Error	352.0		10.3		189.9		9.5	
	Cations							
	K^+		Na^+		K^+		Na^+	
Genotype	2.0	0.15^{NS}	0.65	0.22^{NS}	3.6	3.46^{NS}	0.29	1.06^{NS}
Treatment	11016.4	800.7^{**}	4719.3	1606^{**}	1131.7	1094.7^{**}	287.9	1063.7^{**}
Error	13.8		2.9		1.03		0.27	
	Ca^{2+}		Mg^{2+}		Ca^{2+}		Mg^{2+}	
Genotype	0.38	0.29^{NS}	0.02	0.01^{NS}	0.01	0.66^{NS}	0.04	2.89^{NS}
Treatment	145.6	109.7^{**}	161.9	104.6^{**}	0.6	37.1^{**}	0.037	2.01^{NS}
Error	1.3		1.6		0.02		0.01	
	Transpiration		Transpiration rate		Transpiration coefficient		Water use efficiency	
Genotype	4.82	0.63^{NS}	00.4	3.61^{NS}	48.03	0.51^{NS}	0.0002	4.18^{NS}
Treatment	286.57	37.62^{**}	0.187	169.4^{**}	5434.56	57.62^{**}	0.003	67.71^{**}
Error	7.62		0.001		94.32		0.00004	

Table 24: Analysis of variance of the effect of K^+ substitution by Na^+ on sugar concentrations, sugar yield, white sugar yield, and α-amino-N concentrations of beet of two sugar beet genotypes grown in nutrient solution for 10 weeks

Source	Sucrose		Glucose		Fructose		Sucrose % FW	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Genotype	1330.95	1.85 ^{NS}	0.15	0.8 ^{NS}	0.19	1.85 ^{NS}	0.093	0.12 ^{NS}
Treatment	4771.46	6.62**	1.87	9.68**	0.42	4.04**	2.55	3.34*
Error	720.47		0.19		0.104		0.76	
	α-amino-N concentrations		Sugar yield		White sugar yield			
Genotype	1.8	0.12 ^{NS}	3.25	1.09 ^{NS}	3.68	1.42 ^{NS}		
Treatment	2685.0	176.0**	410.55	138.2**	377.3	145.7**		
Error	15.3		2.97		2.59			

4.2.2 Effect of Ca^{2+} deficiency on the growth of sugar beet plants grown in growth chamber

The major result of the experiment with various K^+/Na^+ nutrition was that the Ca^{2+} concentrations in leaves and beets were reduced in the 4.0 mM Na^+ treatment. A further experiment was conducted, to determine whether the reduced growth was related to Ca^{2+} deficiency.

The typical symptoms of Ca^{2+} deficiency, i.e. small and hooking of young leaves followed by death of growing point, which indicate a defect in cell wall synthesis, was noticed (Photo 3).

Photo 3 Symptoms of Ca^{2+} deficiency:
Hooking of young leaves, followed by death of growing point.

The fresh weight of leaves and beets after 60 days of growth at different levels of Ca^{2+} are presented in Fig. 68. The plant growth was inhibited by the reduction of Ca^{2+} supply, whereas no significant difference was observed between 2.0 mM $Ca(NO_3)_2$ and 2.0 mM $CaCl_2$ treatments. The same trend was observed for leaf and beet dry weights (Fig. 69).

Leaf K^+ concentrations decreased significantly in all $CaCl_2$ treatments compared to 2.0 mM $Ca(NO_3)_2$. But K^+ concentrations of beets decreased significantly at 0.1 and 0.0 mM $CaCl_2$ treatments compared to 2.0 mM $Ca(NO_3)_2$. No significant effect of all $CaCl_2$ treatments was observed for leaf and beet Na^+ concentrations. Leaf and beet Ca^{2+} concentrations decreased significantly at the three low CaCl2 treatments, although the difference between 2.0 mM $Ca(NO_3)_2$ and 2.0 mM $CaCl_2$ treatments was not significant. In contrast to Ca^{2+} concentrations, Mg^{2+} concentrations of leaves and beets increased significantly at the two low Ca^{2+} treatments (Table 25). The Cl^- concentrations of leaves and beets were significantly reduced by decreasing the Ca^{2+} supply compared to 2.0 mM $CaCl_2$ treatments. Leaf and beet NO_3^- concentrations decreased significantly only at 2.0 mM $CaCl_2$. Leaf PO_4^{3-} concentrations were significantly higher at 0.0 mM $CaCl_2$, whereas no significant differences among the treatments were observed in beets. SO_4^{2-} concentrations of leaves was not significantly affected by Ca^{2+} deficiency treatments, although SO_4^{2-} concentrations in beets were significantly increased at 2.0 mM $Ca(NO_3)_2$ and 0.2 mM $CaCl_2$ compared to 2.0 mM $CaCl_2$ treatments (Table 25).

The leaf α-amino-N concentrations increased significantly at two lower $CaCl_2$ treatments. Similarly, the α-amino-N concentrations of beets increased significantly in all treatments of $CaCl_2$ compared to 2.0 mM $Ca(NO_3)_2$ (Fig. 70).

The sucrose and glucose concentrations of beets decreased significantly with the reduction of Ca^{2+} supply compared to 2.0 mM $Ca(NO_3)_2$ or 2.0 mM $CaCl_2$, but fructose concentrations were not significantly affected (Fig. 71 and 72). Sucrose concentrations (% FW) decreased significantly at 0.2 mM $CaCl_2$ (Fig. 73). Sugar and white sugar yield decreased significantly by decreasing calcium supply, whereas there was no significant difference between 2.0 mM $Ca(NO_2)_2$ and 2.0 mM $CaCl_2$ (Fig. 74).

The analysis of variance indicated that the Ca^{2+} treatments had a strong effect on the fresh and dry weights of leaves, and beets and other parameters considered (Table 26 and 27).

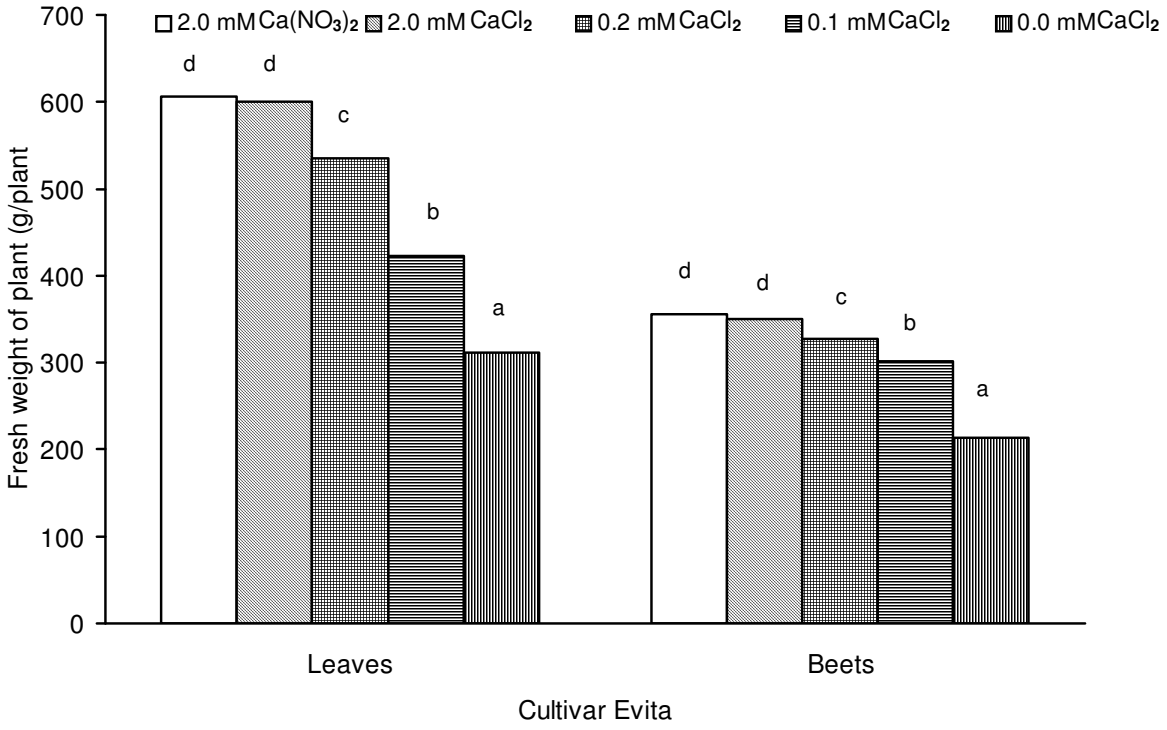

Fig. 68: Effect of calcium deficiency on the fresh weight of leaves and beets of sugar beet plants grown in growth chamber for 10 weeks

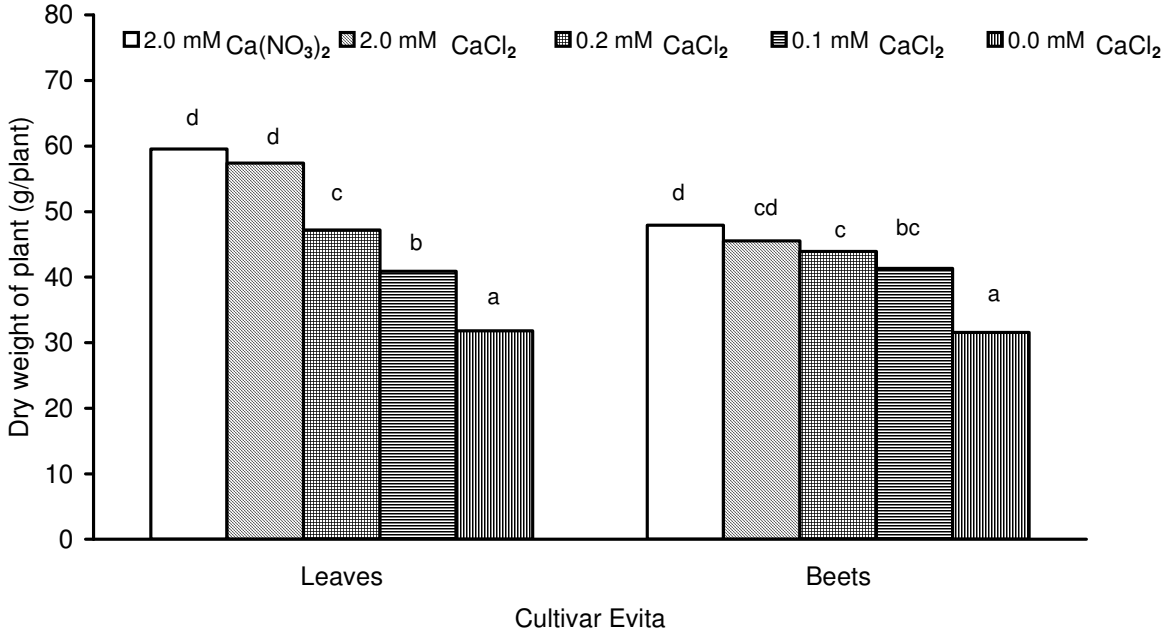

Fig. 69: Effect of calcium deficiency on the dry weight of leaves and beets of sugar beet plants grown in growth chamber for 10 weeks

Table 25: Effect of Ca^{2+} deficiency on the cation and water-soluble anion concentrations of leaves and beets (mg/g DW) of sugar beet plants (cv. Evita) grown in nutrient solution in growth chamber for 10 weeks

Treatments	leaves				Beets			
	Cations							
	K^+	Na^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}
2.0 mM $Ca(NO_3)_2$	79.08 b	0.48 a	12.53 c	11.37 ab	31.0 b	0.20 a	1.19 c	1.26 b
2.0 mM$CaCl_2$	75.83 a	0.47 a	12.48 c	10.33 a	29.5 ab	0.19 a	1.17 c	1.01 a
0.2 mM$CaCl_2$	75.23 a	0.48 a	5.08 b	12.54 b	29.8 ab	0.18 a	0.65 b	1.23 b
0.1 mM$CaCl_2$	74.73 a	0.47 a	4.47 b	12.76 b	29.0 a	0.18 a	0.57 b	1.53 c
0.0 mM$CaCl_2$	74.33 a	0.49 a	1.43 a	14.29 c	29.0 a	0.18 a	0.30 a	1.69 c
L.S.D 5%	3.07	0.05	1.15	1.47	1.6	0.04	0.11	0.17
	Anions							
	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
2.0 mM $Ca(NO_3)_2$	27.97 d	30.15 b	13.68 a	4.22 a	6.74 c	7.67 b	10.33 a	0.47 b
2.0 mM$CaCl_2$	29.28 d	26.14 a	15.27 a	4.40 a	6.09 c	5.51 a	9.63 a	0.22 a
0.2 mM$CaCl_2$	16.15 c	28.44 ab	17.95 ab	4.85 a	4.17 b	6.87 ab	9.44 a	0.41 b
0.1 mM$CaCl_2$	13.84 b	28.02 ab	16.69 a	4.83 a	3.43 ab	7.01 b	9.49 a	0.25 a
0.0 mM$CaCl_2$	11.63 a	27.74 ab	18.10 b	4.85 a	2.85 a	7.43 b	10.44 a	0.28 a
L.S.D 5%	1.52	3.02	2.53	0.79	1.02	1.42	1.32	0.095

Critical values of cation concentrations according to Bergmann (1992):
35- 60 mg K^+/g DW
7-20 mg Ca^{2+}/g DW
3-7 mg Mg^{2+}/g DW

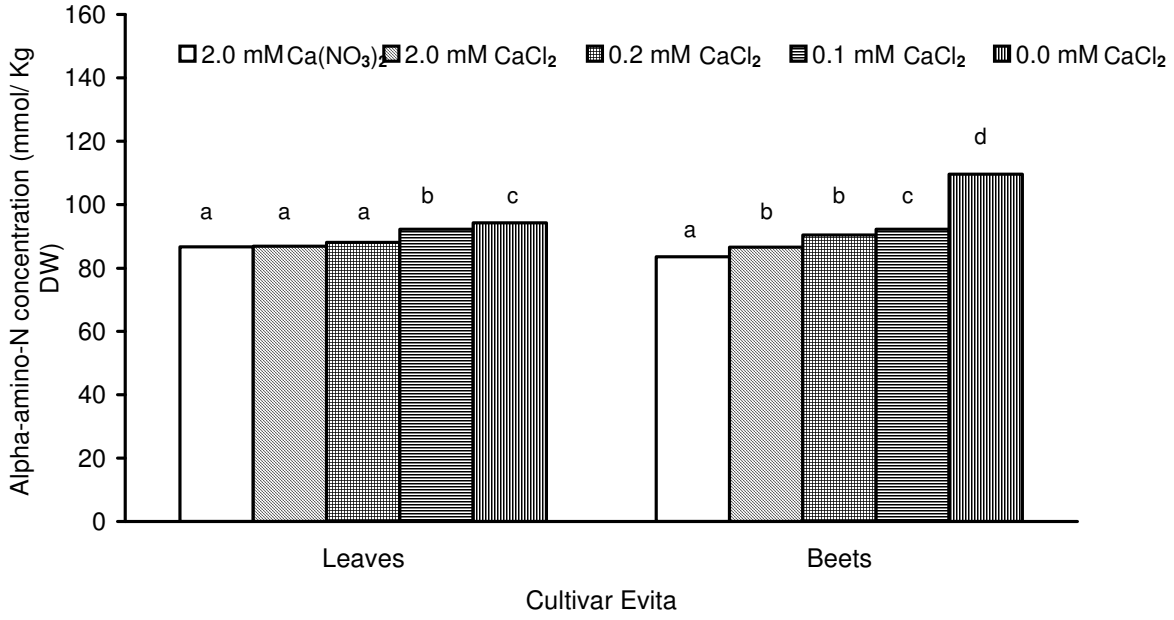

Fig. 70: Effect of calcium deficiency on alpha-amino-N concentrations of beets and beet of sugar beet plants grown in growth chamber for 10 weeks

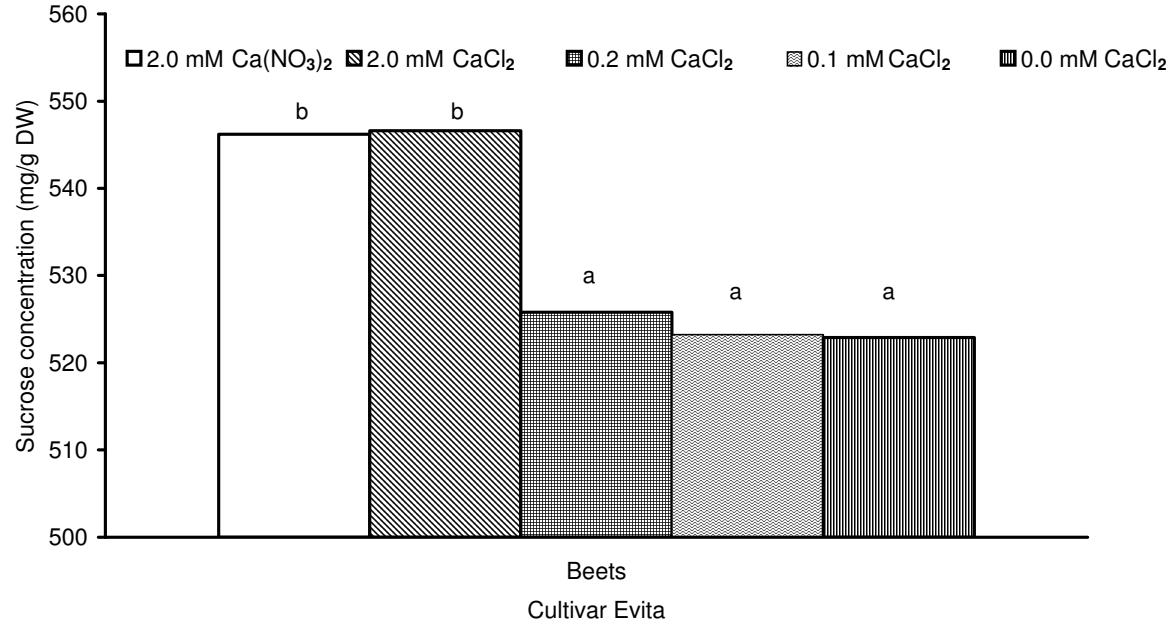

Fig. 71: Effect of calcium deficiency on sucrose concentrations of beets of sugar beet plants grown in growth chamber for 10 weeks

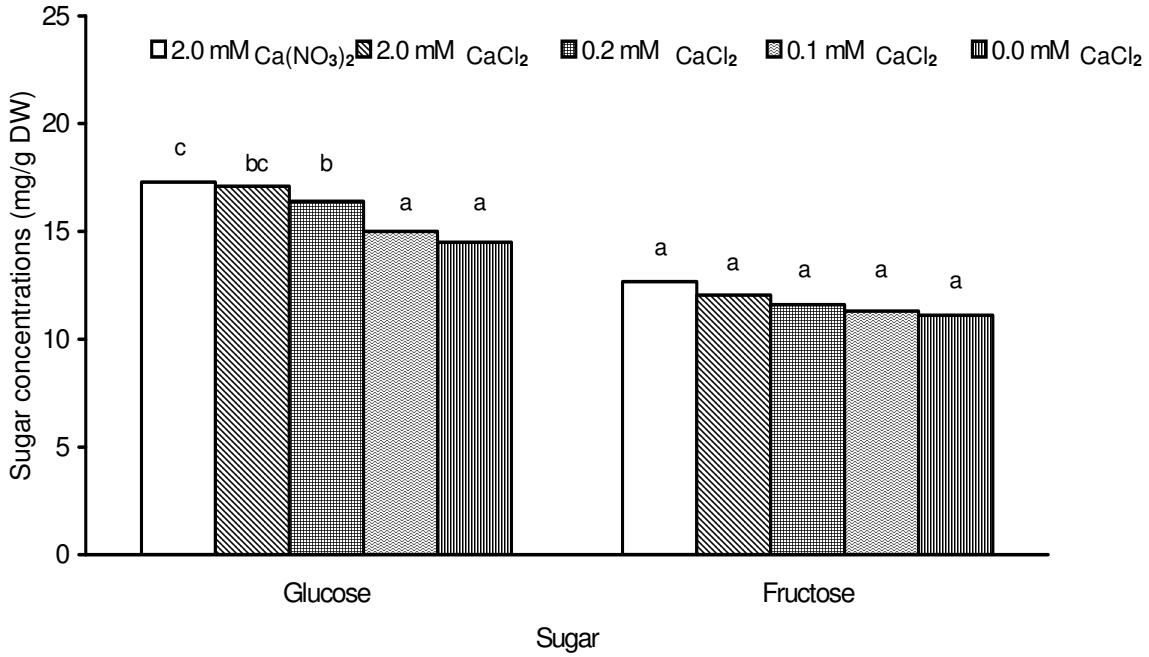

Fig. 72: Effect of calcium deficiency on sugar concentrations of sugar beet plant grown in growth chamber for 10 weeks

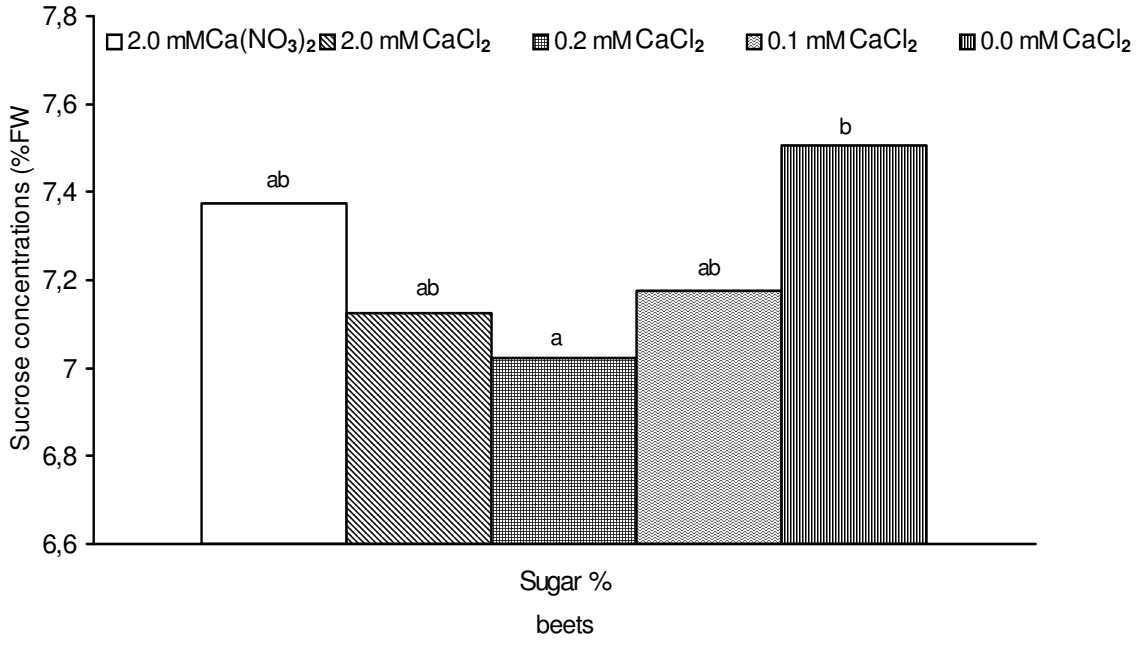

Fig. 73: Effect of calcium deficiency on the sucrose concentrations of sugar beet plant grown in growth chamber for 10 weeks

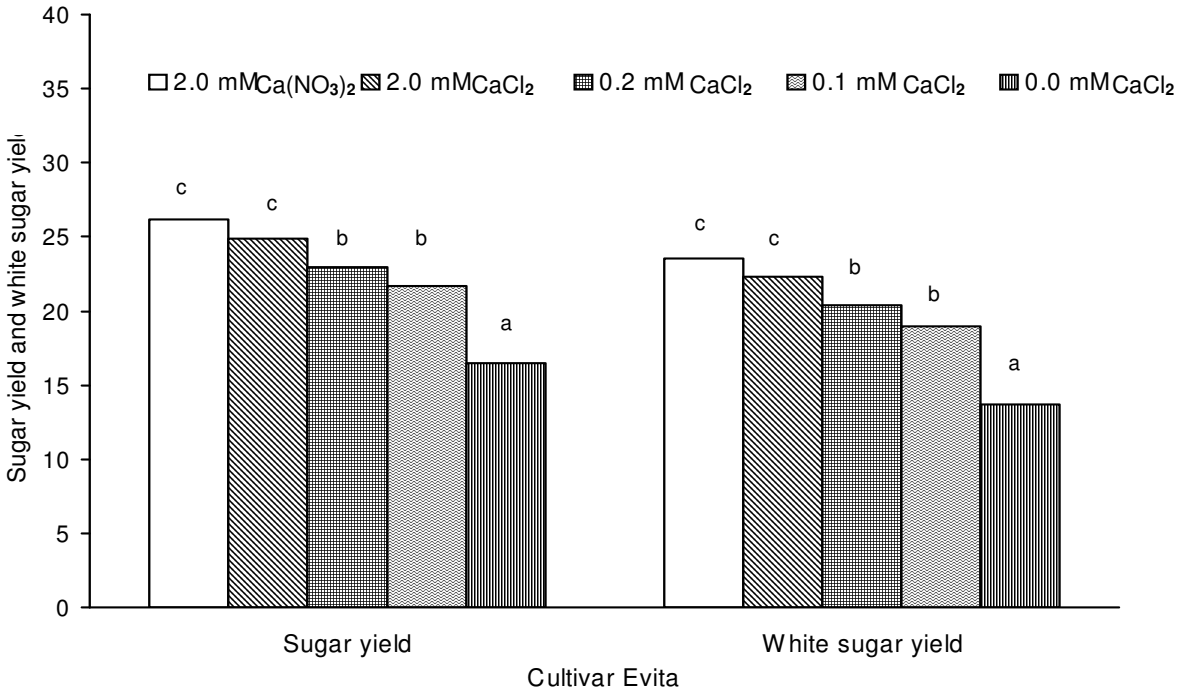

Fig. 74: Effect of calcium deficiency on sugar yield and white sugar yield of sugar beet plants grown in growth chamber for 10 weeks

Table 26: Analysis of variance of Ca^{2+} deficiency on plant growth, α-amino-N concentrations, sugar concentrations, sucrose % FW, sugar yield and white sugar yield of sugar beet plants (cv. Evita) grown in nutrient solution in growth chamber for 10 weeks

Source	Leaf fresh weight		Leaf dry weight		Beet fresh weight		Beet dry weight	
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Treatment	64200.5	153.46**	533.39	52.39**	13390.9	58.58**	160.87	41.43**
Error	418.37		10.18		228.59		3.88	
	Leaf α-amino-N		Sucrose		Glucose		Fructose	
Treatment	46.98	7.66*	606.79	8.27*	7.04	21.18**	1.58	1.23 NS
Error	6.13		73.34		0.33		1.28	
	Beet α-amino-N		Sucrose % FW		Sugar yield		White sugar yield	
Treatment	411.91	57.46**	0.15	1.77 NS	55.72	53.44**	58.34	58.92**
Error	7.17		0.09		1.04		1.5	

Table 27: Analysis of variance of Ca^{2+} deficiency on cation and anion concentrations of sugar beet plant (cv. Evita) grown in nutrient solution in growth chamber for 10 weeks

Source	Leaves				Beets			
	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
	Cations							
	K^+		Na^+		K^+		Na^+	
Treatment	14.38	3.48^{*}	0.0003	0.27^{NS}	2.74	2.44^{NS}	0.0003	0.55^{NS}
Error	4.14		0.001		1.12		0.0005	
	Ca^{2+}		Mg^{2+}		Ca^{2+}		Mg^{2+}	
Treatment	101.44	173.6^{**}	9.02	9.45^{*}	0.61	122.4^{**}	0.3	22.28^{**}
Error	0.58		0.95		0.005		0.013	
	Anions							
	Cl^-		NO_3^-		Cl^-		NO_3^-	
Treatment	275.84	271^{**}	0.67	1.43^{NS}	11.39	24.83^{**}	0.39	5.97^{*}
Error	1.02		0.47		0.46		0.066	
	PO_4^{3-}		SO_4^{2-}		PO_4^{3-}		SO_4^{2-}	
Treatment	2.33	3.73^{*}	0.5	1.83^{NS}	0.097	2.16^{NS}	0.039	9.73^{**}
Error	0.624		0.27		0.045		0.004	

5 Discussion

The extent to which K^+ can be substituted by Na^+ in metabolic processes within the family *Chenopodiaceae* is generally high (El-Sheikh et al., 1967), although it has not been clear to what extent Na^+ can substitute K^+ in sugar beet crop. There is limited knowledge of the comparative effects of these two elements on plant growth or the mechanisms by which they increase sugar yield. It is also not clear, in which metabolic functions K^+ can be substituted by Na^+ and in which metabolic processes Na^+ might be essential or at least more effective than K^+. Potassium is an important univalent cation generally recognized to be indispensable for growth of all plants. It is characterized by high mobility in plants at all levels. K^+ is the most abundant cation in the cytoplasm and it makes a major contribution to the osmotic potential of cells of glycophytic plant species. The role of K^+ in growth and composition of the sugar beet storage root is not restricted to the stimulating effects of K^+ on photosynthesis and the transport of assimilates (Mengel and Haeder, 1977), but also includes aspects of osmo and turgor regulation in the sink tissue itself (Wyn Jones et al., 1983; Beringer et al., 1983). Sodium has been reported to have a stimulatory effect on growth of some *Chenopodiaceae* members (El-Sheikh et al., 1967), but is not generally considered a macronutrient and has not been shown to be essential for all higher plants (Flowers et al., 1977).

The major objective of the present study was to investigate the limiting processes which are affected by water stress and substitution of K^+ by Na^+ in sugar beet without adversely affecting metabolic functions. In addition, the effects of drought and heat on the growth and storage of sugar in two sugar beet cultivars were determined.

5. 1 Plant growth

The experiment related to K^+ and Na^+ fertilization on the growth of sugar beet grown in soil under natural condition exhibited that at the final harvest yield of sugar beet (leaf and beet fresh and dry weights) increased significantly in all treatments compared to control (2.5 g KCl pot^{-1}) for both cultivars (Fig. 4 and 6). The highest yield was observed at a higher level of KCl and NaCl combinations for both cultivars (Fig. 5 and 7). A positive effect of NaCl fertilization on the beet dry weight was

observed for both cultivars at both harvests (Fig. 7). It appears that a balanced K^+ and Na^+ supply is essential for maximum yield of sugar beet. The beneficial effect of Na^+ on growth may be attributed to two effects, namely those on cell expansions and on the water balance in the plants. It is clear that application of both elements together (K^+ and Na^+) increased plant fresh and dry weights more than either element alone. A significant difference of K^+ and Na^+ fertilization was observed on leaf fresh weight and beet fresh and dry weights for both harvests. Genotypes showed a significant difference with regard to leaf fresh and dry weights at both harvests (Table 6). In this regard, El-Sheikh et al. (1967) found that plant growth is the result of interrelated utilization of the different elements concerned in nutrition. Accordingly, the concept of cation balance represents a situation where the addition of an element (in this case Na^+) may cause positive or negative effect on the growth or in some cases no effect, depending on the relative concentrations of other elements (in this case K^+). Marschner and Possingham (1975) postulated that K^+ can be substituted by Na^+ to a large extent in cell expansion and chloroplast multiplication, but K^+ cannot be replaced by Na^+ in chlorophyll formation. The greater cell expansion in the presence of Na^+ compared to K^+ in sugar beet could be caused by different effects of both ions on carbohydrate metabolism. Where Na^+ is almost as effective as K^+ is cell expansion. Marschner et al. (1981 a) reported that sugar beet as a member of the family Chenopodiaceae is relatively salt-tolerant except the seedling stage (Mercado, 1970). It was characterized by high accumulation of both sodium and chloride in the shoot when grown on saline substrates **(**Lessani and Marschner, 1978). Marschner et al. (1981 b) found that in sugar beet Na^+ can replace K^+ to a large extent and that Na^+ has a specific growth-stimulating effect, which differs between genotypes within this species. Na^+ stimulated shoot growth more than storage root growth, although to a different degree in three genotypes. This change in the relative "sink-strength" could be the result of a different effect of Na^+ and K^+ on the phytohormone level and of a shift in the phytohormone balance by Na^+. In less specific processes, such as raising cell turgor, some replacement is possible. In halophytes, the role of K^+ in osmotic adjustment of the vacuole is largely replaced by Na^+. Also, Hampe and Marschner (1982) reported that the effect of Na^+ on growth and metabolism depends upon the plant species. This is reflected in the classification of plants into so-called "natrophilic" and "natrophobic"

species. Marcussen and Smed (1996) revealed that Na^+ is an essential nutrient and best in combination with K^+. The equivalent quantity of K^+ alone (200 kg K^+ ha^{-1}), did not show the same beneficial effect as the combination of 100 K^+ + 100 Na^+ ha^{-1}. In same crops, Na^+ has the capacity to prevent or to reduce considerably the occurrence of K^+ deficiency. Buschmann et al. (2000) postulated that the interaction between K^+ and Na^+ uptake might represent a key factor in determining the Na^+ tolerance of plants.

Our result related to the effect of water stress and substitution of K^+ by Na^+ on the growth of sugar beet, showed that water stress (40% WHC) reduced leaf and beet fresh weights compared to 70% WHC at the first harvest. But, leaf and beet fresh weight increased significantly in all treatments of K^+ substitution by Na^+ related to 100% K^+ application (Fig. 14 and 18). Leaf dry weight was not significantly affected in all treatments, whereas beet dry weight was significantly affected by water stress and K^+/Na^+ substitution. The effects of water stress and different treatments of K^+ substitution by Na^+ on these parameters are stronger than the genotypes (Table 13). In this respect, Marschner et al. (1981 a) reported that at low NaCl concentrations the stimulatory effect of Na^+ on plant metabolism still dominated over the inhibitory effect of the higher salt concentration. But the growth depression at higher NaCl concentrations was particularly high immediately after onset of the salt treatment and then declined gradually. This pattern could be either the result of lower salt tolerance of young sugar beet plants (Mercado, 1970) or of metabolic adaptation to higher cellular NaCl concentrations. Morgan (1984) found that many important physiological processes of plants such as leaf enlargement, stomatal opening and photosynthesis are directly affected by reduction in leaf water potential resulted in a severe reduction both in growth and yield of plants. Drought often stimulates root growth because inhibition of shoot growth in a drought-stressed plant makes more carbohydrate available to the roots.

When water stress develops in sugar beet, plants experience low leaf water potential and relative water content, the rate of growth of leaves and storage roots declines resulting in slower cell expansion and smaller stomatal conductance. This means less carbon dioxide uptake for dry matter production (Milford et al., 1985 a). Hang and Miller (1986) found that on a loam soil, maximum dry matter production

occurred at irrigation rates equivalent to 40 to 50% of estimated evapotranspiration at the final harvest. On the sandy soil, with limited water, dry matter production increased with increasing water applied up to about 85% estimated evapotranspiration. Similarly, Marschner (1995) found beneficial effects of K^+ and Na^+ fertilizers on yield of sugar beet under drought conditions. The positive effects of Na^+ applications on yield of sugar beet were observed when K^+ was sufficiently supplied. The reason for the beneficial effect of Na^+ has been related to an improved drought resistance when the water supply is limited and stimulation of assimilate transport into the beet root. Scott and Jaggard (1993) found that sugar beet is generally considered to be a drought-tolerant crop. For sugar production in dry areas (where irrigation is essential for production) yield is more closely related to the amount of water available and the dryness of the atmosphere. Sugar yield is directly related to the interception of solar radiation, determined largely by the rate of development of the crop canopy maintenance of functional leaf area. Also, Pidgeon and Jaggard (1998) found that the mean annual loss of sugar production in the UK was 141000 tonnes per year or 10.5%. Losses in individual years varied from zero to 25%. This means that drought stress is the largest single constraint of yield of sugar beet. Also, Duggan et al. (2000) found that growing season environments may be characterized by the limitations imposed by stress at different stages of crop development. Drought stress has been shown to retard the formation of the yield component that is most actively developing at the time of stress.

Water stress reduced sugar beet growth by reducing the leaf and beet fresh weights. At the first harvest, the mean reductions were 30-38% for leaves and 25-37% for beet fresh weight. Also the mean reductions were 16-27% for leaves and 12-36% for beets dry weight (Table 9). This decrease was primarily due to the result of a reduction in leaf size resulting from a reduction in cell expansion due to a fall in turgor pressure in droughted plant (Lawlor and Milford, 1973). Carter et al. (1980) found that sugar beet is not normally irrigated, except under severe drought conditions and sugar beet can withstand much drier conditions than other crops without affecting quality or yield significantly. Normally less than 5% of the crop will receive any irrigation. However, deficit irrigation of silt loam soil from August through October reduced leaf

growth of sugar beet, increased sucrose concentration in the root and decreased fresh root yield. Noghabi and Williams (1998) postulated that dry matter production of sugar beet was reduced up to 36% by water stress. Sugar beet cultivars present different responses to moisture stress. The fact that interaction effects between watering regimes and sugar beet cultivars were significant for total dry matter as well as root dry weight suggests that there is the possibility to find beet cultivars relatively tolerant to water stress.

Environmental constraints are major factors in productivity of crops in many regions of the world (Kronstad, 1996). Drought and heat are particular problems, occurring episodically in some regions and ubiquitously in others (Gusta and Chen, 1987). The direct effects of high temperature stress depend on the crop species and its adaptability. Sugar beet crop is cultivated successfully in a wide range of climates on many different soils. The crop is grown with supplementary irrigation in regions where low rainfall previously prevented its cultivation. Also, sugar beet is the most important sucrose-producing crop in temperate regions of the world. In the Mediterranean region, adequate sugar beet production requires supplementary irrigation, but in recent years drought stress has become a major constraint to sugar beet cultivation even in Northern Europe, causing serious reductions in productivity (Jaggard et al., 1998; Pidgeon et al., 2001). Although sugar cane is the major sugar crop in Egypt, sugar beet area has been extended more than anticipated because sugar cane has higher water consumption and needs a longer season than sugar beet. But, under arid and semi-arid conditions (e.g. Egypt) high temperature and drought are the most important stress affects for sugar beet production, therefore the an experiment was carried out to investigate the effect of drought and heat on the yield and quality of sugar beet.

Results concerning the effects of drought and heat on the growth of sugar beet revealed that at high temperature, leaf and beet fresh weights were significantly decreased compared to low temperature for both cultivars. Furthermore, drought (40% WHC) caused a significant decrease in plant growth relative to plants grown under watered conditions (70% WHC) at high temperature (Fig. 38-41). The analysis of variance showed that drought, heat and genotype had a significant effect on plant growth (Table 19). In this regard, both drought and high temperature adversely affect

photosynthesis in crops. Drought rapidly reduces expansion of leaves and stomatal conductance and may eventually impact primary events in the photosynthetic process (Passioura, 1994). Both factors decreased photosynthesis by different mechanisms. Stomata closed when plant were stressed for moisture at moderate or high temperature. Adverse effects resulted more from resistance to CO_2 exchange than from injury to the plant photosynthetic apparatus (Gusta and Chen, 1987). High temperature, in contrast, was most damaging to Photosystem II and had little effect on stomatal aperture when plants were well- watered (Al-Khatib and Paulsen, 1990). Reduction in leaf area through both drought and heat probably occurred by different processes. Stomatal closure may control or initiate senescence of leaves causing the viable area for photosynthesis to decrease in drought-stressed plants. The yield losses due to high temperature are large and are often combined with losses from other environmental stresses. By increasing the rate of plant development, warmer temperature also reduce the length of the growing period thereby reducing the yield potential (Entz and Fowler, 1990). Milford et al. (1980) found that leaf growth and development are strongly influenced by temperature. In sugar beet, final yields of dry matter and sugar are proportional to the total amounts of radiation intercepted by crops during growth. Also, Werker (1993) found that, the rate of canopy growth is an important consideration for sugar beet grown in temperature climates. Early growth and leaf expansion of sugar beet in the UK for example is limited primarily by temperature, however, later on there is a switch from dependence on temperature to one on solar radiation. Xu and Huang (2000) postulated that in warm climate regions, plant roots often are exposed to soil temperatures that reach injuriously high levels, which strongly influences shoot growth and even survival of whole plants. High soil temperatures inhibit growth and physiological activities of shoots and accelerate leaf senescence. Leaf injury under high soil temperatures has been attributed to direct inhibition of root growth and activity and, limitation of water and nutrient supplies to the shoot. Hall (2001) reported that high temperature can have direct damaging effects associated with hot tissue temperatures or indirect effects associated with the plant-water-deficits that can arise due to high evaporative demands. Evaporative demand exhibits near exponential increases with increases in day-time temperatures and can result in high transpiration rates and low plant water potentials. During the vegetative

stage, high temperature can cause damage to components of leaf photosynthesis, reducing carbon dioxide assimilation rates compared with environments having more optimal temperature.

Our result concerned with the effects of K^+ substitution by Na^+ in nutrient solution on the growth of sugar beet demonstrated that the fresh weight of leaves and beets increased significantly in all treatments of K^+ substitution by Na^+ compared to 4.0 mM KCl for both cultivars (Fig. 53 and 55). However, this increment was not observed for leaf and beet dry weights. At 4.0 mM NaCl, beet fresh and dry weights decreased significantly compared to 4.0 mM KCl (Fig. 55 and 56).

The results indicated that a certain amount of K^+ is always required for high yield of sugar beet. If this amount is not available, the addition of Na^+ may even aggravate the symptoms of element deficiency. Na^+ can substitute K^+ in sugar beet grown in the soil, if the sugar beet supplied with sufficient K^+. On the other hand, if K^+ application is limited during a K^+ substitution by Na^+, Ca^{2+} uptake will be decreased, since Na^+ may block the unspecific channel for Ca^{2+} uptake (Demidchik et al., 2002). Also, the response of sugar beet to Na^+ is further complicated in experiments using soils, due to the relatively high Na^+ content in the plants already without additional Na^+ supply. Therefore, we designed a water culture experiment to control the K^+ and Na^+ supply, since in experiments with loamy soils there is still K^+ released. In this regard, El-Sheikh and Ulrich (1970) postulated that Na^+ significantly increases growth of sugar beet crop in solutions containing both low or high K^+ concentration and sugar beet plants remained healthy with no symptoms of K^+ deficiency. According to authors, Na^+ may affect the growth of plants by at least three modes of action. First, under low K^+ conditions they may cause a redistribution of K^+ from old to young leaves or from petioles to blades. Second, they may maintain a favorable cation balance in the cell for various enzymatic reactions. Third, they may have an essential role in the growth of plants. A significant increase of sugar beet growth when Na^+ is added to a high K^+ medium may imply a direct effect of Na^+ on the subcellular level, possibly on the enzyme systems. However, Although the specific plant functions in which Na^+ replaces K^+ under low K^+ stress are unknown, the possibility that Na^+ replaces K^+ in non-specific functions in plant cell vacuoles has been suggested. Thus,

the extent of Na^+ substitution for K^+ would depend on Na^+ uptake by plant roots and subsequent translocation to the shoots. The salt-tolerant genotype had greater Na^+ substitution capacity when K^+ was in limited supply. Also, Hasegawa and Yoneyama (1995) found that the growth of sugar beet roots was depressed with treatments of 0.04 and 0.01 mM K^+, no leaf injury was observed, and a slight decrease in K^+ concentrations. It appears that K^+ cannot be replaced by Na^+ in certain functions. On the other hand, Scherer et al. (1982) found that the poor growth of plants observed under conditions of K^+ deficiency is obviously directly related to the effect of K^+ on the plasmalemma located ATPase in meristematic tissues. There is evidence that this effect of K^+ is the most sensitive of all the metabolic effects of K^+.

In our experiment concerned with the effect of various concentration of Ca^{2+} on the growth of sugar beet cultivar, results revealed that the fresh and dry weights of leaves and beets reduced significantly by decreasing Ca^{2+} supply (Fig. 68 and 69). The analysis of variance indicates that the Ca^{2+} deficiency treatments had a strong effect on fresh and dry weight of leaves and beets. Lynch and Läuchli (1985) postulated that the particular role of Ca^{2+} in increasing salt resistance of plants is well documented, as is the induction of Ca^{2+} deficiency in plants grown in saline substrates. This ameliorating effect of Ca^{2+} is in accordance with its functions in membrane integrity and control of selectivity in ion uptake and transport. High Na^+ concentrations in the substrate inhibit uptake and transport of Ca^{2+} and may therefore induce Ca^{2+} deficiency in plants growing in substrate with low Ca^{2+} concentrations. Accordingly at a given high NaCl concentration, increasing Ca^{2+} concentrations can very much enhance growth and prevent Na^+-induced calcium deficiency. Morgan (1984) postulated that calcium is deposited in plants cell walls during their formation; it is required for the stability and function of cell membranes and acts as a type of cementing agent in the cell walls in the form of calcium pectinate. Calcium pectinate is like glue binding adjacent cells together so if inadequate calcium is not transported during cell formation, tissues become less stable and are prone to disintegration. Ca^{2+}, once incorporated into plant tissue is immobile so a constant supply is necessary for continued growth. Concentrations of Ca^{2+} are higher in older foliage, so it is the newer growth which first shows deficiency symptoms. Ca^{2+} also plays a role in activating enzymes, regulating

the flow of water movement in cells and is essential for cell growth and division. Ca^{2+} also helps as a buffer when excesses of other elements are presented and is therefore an important component of plant root structure.

5. 2 Water relations

Water is essential for crop production, and any shortage has an impact on final yields. At present, owing to the global expansion of irrigated areas and the limited availability of irrigation water, there is a need to optimized water use efficiency in order to maximize crop yields under frequently occurring situations of deficit irrigation. Water is the major factor limiting crop yield in many regions of the world. Even where water for irrigation is currently plentiful, there are increasing concerns about future availability (Falkenmark, 1997). Sugar beet crop probably exposed to extended periods of drought stress during growth season in the arid and semi-arid regions. Drought and heat stress cause declines in sugar beet quality that has been associated with reductions in beet yield. Dry and hot environments induce abnormal transpiratal water loss which has a cooling effect but also can cause rapid cell desiccation (Nobel, 1988).

According to the effect of water stress and K^+ substitution by Na^+ on evapotranspiration (ET) of sugar beet plants, our results indicate that evapotranspiration was higher at 70% WHC than under water stress (40% WHC) at the first harvest (Fig. 22). Furthermore, evapotranspiration increased significantly by increasing of K^+ substitution for the cultivar Sofie only at 70% WHC for both harvests (Fig. 23 and 24). Under water stress, evapotranspiration and evapotranspiration rate (ER) reduced significantly in Na^+ supplied compared to K^+ supplied plants (Fig. 22 and 24). Water use efficiency (WUE) of beets increased significantly at 50 and 75% of K^+ substitution under water stress for two cultivars (Fig. 27). It is evident that, Na^+ increased the evapotranspiration at high water availability than plants supplied with K^+, but this was not observed under limited soil water conditions. Therefore, we conclude that Na^+ can substitute K^+ in the metabolic processes and stomatal regulation in sugar beet if the beets receive some K^+ from the soil. Our results were in agreement with the results of Hampe and Marschner (1982) who suggested that Na^+ usually increases the water consumption of the plants. This is not only the result of an increase

in leaf area, but also of a specific decrease in water use efficiency. At higher water availability, Na^+ supplied plants consumed more water may be due to larger leaf area and increased stomatal number. However, it is likely that the faster response of the stomata from the Na^+ treatment to water shortage is more important for the water balance. This could be due to a more rapid efflux of Na^+ compared to K^+ from the guard cells. When the water availability was lowered, the water consumption remained similar in Na^+ supplied plants but increased 60% in plants supplied with K^+. Lawlor and Milford (1973) reported that the Na^+ treated plants with drought stress; the stomatal resistance to evapotranspiration rose more rapidly but declined more slowly after stress release than in K^+ supplied plants. Thus, drought stress had no effect on the water use efficiency in the plants supplied with Na^+ but decreased the water use efficiency of plants supplied with K^+ only. Sugar beet plants appear to control their water balance poorly; they develop small leaf water potential under slight transpirational demand even when water is freely available to the roots. It is not known whether this is due to poor response of stomata to leaf water, to slow absorption of water by the roots or to large resistance to water movement through the plant. It is interesting to note that drought reduced the transpiration rate which implies that stomatal conductance was reduced, a possibility supported by the CO_2 uptake measurements. Ehleringer (1993) and Thumma et al. (1998) reported that high water efficiency is cosidered to be a critical trait contributing to high productivity under water stress conditions. Jackson and Ezra (1995) reported that water stress may cause closure of stomates and reduction in CO_2 supply and this may in turn lead to increase visible reflectance. Zayed and Zeid (1998) reported that water stress reduces nutrient uptake by roots and transport from roots to shoots because of restricted transpiration rates and impaired active transport and membrane permeability.

It is known that K^+ plays an important role in cell osmotic and turgor changes in guard cells during stomatal movement. Under light conditions, an increase in K^+ concentrations in the guard cells brings about the uptake of water and guard cells produce abundant ATP in photosynthetic phosphorylation, thus supporting the active K^+ uptake mechanism with sufficient energy (Humble and Hsiao, 1970). K^+ therefore accumulates in guard cells in considerable concentrations and the resulting high turgor

pressure causes the opening of stomata. In the dark, loss of turgor in the guard cells and closure of the stomata is associated with an efflux of K^+. In leaves, cell turgor provides the driving force for expansion growth and for stomatal functioning, through the latter, it influences photosynthetic activity. In sugar beet, Na^+ can replace K^+ in this role. Na^+ replacement of K^+ in guard cells decreases the osmotic potential in guard cells and induced water uptake from leaf cell. Then turgor increases in guard cells and stomatal cells open. We assume that Na^+ can substitute K^+ in stomatal cells regulation. But, Na^+ may not be so efficient in closing regulation of the stomatal cells, since Na^+ is not transported out of stomata cells in order to close the cells compared to K^+. Therefore leaves may transpire more water in a Na^+ treatment than in a K^+ treatment. Willmer and Mansfield (1969) reported that Na^+ was more effective than K^+ in stomatal opening of isolated epidermis of *Commelina communis*. However, Garrec et al. (1983) have not observed a significant change in Na^+ content between open and closed stomata of *Vicia faba* and *Commelina communis*.

Results related to the effects of drought and heat on the growth of sugar beet revealed that the evapotranspiration, evapotranspiration rate and evapotranspiration coefficient were significantly higher at high temperature compared to low temperature. The high temperature may cause stomatal closure which probably results from enhanced respiration and increased levels of CO_2 in the stomatal cavities. High temperature is also often associated with high water consumption. No significant effect was observed between two water treatments at low temperature (Fig. 42-44). Water use efficiency of beets reduced significantly in all treatments of drought and heat (Fig. 45). The effect of drought and heat had significant effect on water relations, whereas no significantly different of genotype was obtained (Table 20). In this regard, Yfoulis and Fasoulas (1978) found that at higher temperature the rate of respiration increases more rapidly, thus decreasing the net assimilation and repressing the growth. The water uptake is increased by raised temperature because the viscosity of water decreases with increased temperature, which increases the capillary diffusion rate of water flowing into the plant. High temperature also increased the active uptake of water, as well as the water transport through the root system (Yfoulis and Fasoulas, 1978). Shah and Paulsen (2003) found that the high temperature interacted with

drought stress by exacerbating most plant responses to moisture deficiency. High temperature accentuated injury to photosynthesis, leaf area and negated the positive effect on water use efficiency from drought stress. This interaction action is undoubtedly physiological in nature and has important practical applications. High temperature, in contrast, aggravated plant responses to drought by injuring photosynthetic components, increasing consumption of assimilates, and preventing osmotic adjustment (Morgan, 1980). Transpiration from plants in controlled conditions is determined mainly by the gradient in water vapour potential of the air and is hardly affected by temperature. Drought induced reduction in the rate of transpiration was noted in cotton (Leidi et al., 1993). Yan Rensburg and Krüger (1993) reported that WUE declined significantly in tobacco under drought. Regulation of transpiration controls Na^+ translocation to the leaves. Passive ion uptake was related to transpiration in rice plant (Hirai et al., 1985), but Naito et al. (1994) showed that higher transpiration led to low Na^+ contents in shoot in rice plant. Results of this experiment led us to interpret that under water deficit resulted in higher WUE which seems to be a desirable trait under drought condition and such an affect might be due to reduction in stomatal conductance and transpiration rate that ultimately led to maintain better water status of leaves under stress conditions.

Results concerned with the effects of K^+ substitution by Na^+ in nutrient solution demonstrated that increasing K^+ substitution has resulted in significant increase of transpiration (T) compared to 4.0 mM K^+ (control) (Fig. 57). Transpiration rate (TR) and transpiration coefficient (TC) increased significantly at low K^+, low mM Na^+, low K^+ + Na^+ and high Na^+ supply compared to 4.0 mM K^+ treatment for both cultivars (Fig. 58 and 59). Water use efficiency (WUE) of beets reduced significantly by increasing K^+ substitution compared to control treatment for both cultivars (Fig. 60). In this respect, Jennings (1976) reported that Na^+ simultaneously increases leaf succulence in plants grown at high proportion of K^+ substitution by Na^+. This succulence was caused by replacement of K^+ by Na^+ in the plant tissue. Na^+ may either increase sucrose concentration within the leaf cells (Hawker et al., 1974) and/or preferentially accumulate Na^+ (compared to K^+) in the vacuoles. As a result of these changes a more rapid decrease in cellular osmotic potential and, at sufficient water

availability, an increase in rates of cell expansion can be expected following an increase of leaf succulence. Zehler et al. (1981) also, found that both Na^+ and Cl^- increase the succulence of plants. This was reflected by the significant increase of transpiration in high Na^+ supply treatments. On the other hand, low K^+ supply, apart from increasing transpiration from the plants, also inhibits water uptake. It regulates the water economy of plants in a positive sense: plants lacking K^+ have a higher transpiration coefficient (unproductive water consumption). Since low K^+ supply reduces the ability of plants to prevent excessive transpiration in hot, dry weather, plants lacking this element are not only prone to wilting, but also have lower net assimilation. The lower water loss of K^+-treated plants is due to a reduction in transpiration rate, which not only depends on the osmotic potential of the mesophyll cells but is also controlled to a large extent by the opening and closing of stomata. Both elements (Na^+ and Cl^-) are known to increase succulence of plants. This was reflected by the significant increase in the water content of the vegetative tissue when Na^+ substituted K^+.

5. 3 Leaf area

It is known that leaf area development depends on environmental factors such as temperature, light, water and nutrient supply (Goodman, 1963). Draycott and Farley (1971) showed that Na^+ applied to the soil increased the leaf area of sugar beet early in the season. Plant growth and sugar yield are also increased by application of NaCl. The rate of leaf area growth of sugar beet is slow at the beginning of the season followed by a faster, more or less linear increase in weight up to the time of maximum leaf area. Afterward, the leaf area sometimes decreases because old, large leaves die and are replaced by new, smaller leaves (Milford et al., 1985 b). The increase of sugar beet leaf area and the efficiency of solar radiation interception are small during the early season. This is considered to be of great importance with the sugar beet crop for agronomic practices. The increase of leaf area per plant in the period between establishment and full leaf cover, usually results in increased sugar yield.

Our results clearly showed that leaf area increased significantly by increasing K^+ substitution. The highest leaf area was observed at 50% K^+ substitution for both cultivars under two water treatments (Fig. 29). It is evident that water stress decreased

leaf area per plant mainly by affecting cell expansion. On the other hand, plants without Na^+ treatments have the lowest leaf area than treated plants with Na^+ during the vegetative period, but leaf senescence was greater on plants with Na^+ and/or K^+ than on plants without either. Na^+ increased the leaf area, whereas drought stress reduced it. Our results are in agreement with the findings of Lawlor and Milford (1973) who reported that Na^+ increased the water content of leaves and improved the water status of the plants under water stress. Na^+ increased the leaf area via an increased rate of cell expansion. Similarly, Durrant et al. (1978) found that water stress decreased leaf area per plant mainly by affecting leaf expansion. Particularly under field conditions, supply of additional Na^+ seems to stimulate growth and sugar yield, primarily by improving the water balance of the plants and by increasing the leaf area. Both of these effects have been shown to increase sugar yields, the extent depending on conditions and the magnitude of the crop's physiological response to Na^+ (Kirkby et al., 1987). Hampe and Marschner (1982) postulated that the beneficial effect of Na^+ on growth may be du to cell expansion and improved water balance in the plants. Na^+ not only replaced K^+ in the vacuoles but also accumulated in vacuoles and contributed to the osmotic potential and hence to turgor and cell expansion. Leaf area, leaf thickness, and succulence thus increase as K^+ is replaced by Na^+ as a nutrient source. Similarly, the beneficial influence of Na^+ on the water status of the sugar beet crop is probably to responsible for the increase of leaf area early in the season and so increases light interception. It also seems possible that the partial replacement of K^+ by Na^+ may favorably influence both phloem loading and unloading and hence the strength of the sink and sugar yield. Noghabi and Williams (1998) reported that the main effects of watering regimes on leaf area were significant, such that water stress reduced leaf area by 84%. However, after re-irrigation there was no significant difference between stressed and irrigated treatments. Pospisilova et al. (2000) reported that water deficit reduces growth, and leaf area development. Stomatal closure decreases the CO_2 influx which limits photosynthesis under mild water stress and supports photoinhibition under high irradiance. Recently, Bnhassan-Kesri et al. (2002) postulated that drought stress is the main limiting factor of plant cell growth, induces several effects including reduced cell division and growth rates. Leaves which play a

central role in gas exchange are strongly affected by drought stress, while stem expansion depends among species.

5. 4 Ion concentrations

The experiment related with the effect of K^+ and Na^+ fertilization on the growth of sugar beet showed that K^+ concentrations of leaves and beets increased significantly due to increase in KCl application. The Na^+ concentrations of leaves and beets increased significantly for both harvests when NaCl was applied. In contrast to Na^+ concentrations, Ca^{2+} and Mg^{2+} concentrations of leaves and beets were slightly affected by different KCl and NaCl applications (Table 2 and 3). It is worth to mention that Na^+ increases the K^+ uptake in the sugar beet plants. Similarly, Na^+ concentrations were increased by increasing Na^+ supply. However, Ca^{2+} and Mg^{2+} concentrations declined due to cation competition. The data presented in Table 4 and 5 show that leaf Cl^- concentrations were significantly increased in all treatments of K^+ and Na^+ fertilization for both cultivars compared to the 2.5 g KCl treatment. The highest Cl^- concentrations of leaves and beets were obtained at 5.0 g KCl + 3.9 g NaCl treatment for two cultivars for both harvests. On the other hand, NO_3^-, SO_4^{2-} and PO_4^{3-} concentrations of leaves and beet were decreased by increasing K^+ and Na^+ combinations (Tables 4 and 5). In this regard, Marschner et al. (1981 a) found that increasing NaCl supply depressed the levels of K^+ and Na^+ and led to steep increases in levels of Na^+ and Cl^- a pattern which is typical for relatively salt tolerant species such as sugar beet. Haneklaus et al. (1998) studied the effect of Na^+ fertilization on yield and quality of sugar beet when K^+ was sufficiently supplied and found that NaCl fertilization increased significantly uptake of Na^+ and Cl^- and decreased uptake of K^+ of sugar beet. Koyro (2000) suggested that salt-induced changes of ion relations can be tolerated because Na^+ and Cl^- concentrations are relatively low in the cytoplasm as compared to the vacuole. The Na^+ and Cl^- accumulations into the leaf tissues did not lead to toxic effects because of storage of these ions in the vacuoles. The sea beet was able to balance the low external water potential and generated turgor by the accumulation of high internal Na^+ and Cl^- concentrations in the leaves. However, the specificity for the uptake of K^+, Mg^{2+}, and Ca^{2+} was not sufficient to hinder a dilution of these ions at tissue level.

Our results concerned with the effects of water stress and K^+ substitution by Na^+ on the growth of sugar beet showed that all cation concentrations were higher in the water stressed plants relative to watered plants (70 % WHC). Leaf and beet K^+ concentrations decreased significantly by increasing of K^+ substitution by Na^+ for both cultivars in two soil moisture levels. Na^+ concentrations of leaves and beets increased significantly due to increase K^+ substitution. However, Ca^{2+} and Mg^{2+} concentrations of leaves and beets were decreased by increasing K^+ substitution. At the first harvest leaf Cl^- concentrations reduced significantly at 50% K^+ substitution only for cultivar Sofie under two water treatments. Similarly, beet Cl^- concentrations decreased significantly at 75% K^+ substitution at 70 % WHC for both cultivars (Table 10 and 11). It is clear that the response of plant to K^+ supply was higher when soil moisture is high suggesting more K^+ was made available to the plants under high available water. In sugar beet, Na^+ is readily translocated to the shoots, where it replaces most of the K^+ in various metabolic functions. On the other hand, Na^+ decreased the concentration of K^+ in leaves and beets. It appears from our study that water stress had a strong effect on plant growth, cations, anions, α-amino-N and sugar concentrations for both harvests (Table 14, 15 and 16). In this respect, Marschner et al. (1981 a) reported that sugar beet was characterizes as "salt includer", i.e. utilization of both Na^+ and Cl^- for osmotic adjustment of the cells. But it has been maintained that the cytoplasmic concentration of both Na^+ and Cl^- has to be kept low in order to avoid inhibitory effects of these ions on enzyme activities in halophytes or halophilic species exposed to high NaCl concentrations. Martin-Olmedo et al. (1999) reported that Na^+ was the only element whose concentration in the leaf blades of sugar beet was increased as a consequence of residual fertilizer treatments. PO_4^{2-}, K^+, Ca^{2+} and Mg^{2+} concentrations were always within the recommended ranges. Thus, besides N, Na^+ may be a frequent constraint for cropping sugar beet under arid and semi-arid conditions where the element is often abundant and where repeated and excessive fertilization may enhance Na^+ uptake, leading to a detrimental effect on sugar beet quality.

The effect of drought and heat on cation concentrations our results indicated that K^+ concentrations of leaves were significantly decreased by high temperature only under water stress for both cultivars. In beet K^+ concentrations decreased significantly

at 70% WHC only for cultivar Sofie. At high temperature, Na^+ concentrations of leaves reduced significantly under water stress for both cultivars. Similarly a significant effect of heat was also observed for Ca^{2+} and Mg^{2+} concentrations of leaves and beets of both cultivars (Table 17). Leaf and beet Cl^- concentrations were not significantly affected by drought and heat. Leaf and beet NO_3^- concentrations decreased significantly under heat stress compared for two water treatments for both cultivars. PO_4^{3-} concentrations of leaves were significantly decreased at high temperature only for cultivar Evita. Leaf and beet SO_4^{2-} concentrations reduced significantly at high temperature in two water treatments (Table 18). The analysis of variance showed that heat had a significant effect on the K^+ of beet and Ca^{2+} and Mg^{2+} concentrations and leaves and beet. However, the genotype had significant affect for K^+ and Mg^{2+} concentrations of beets and Ca^{2+} concentrations of leaves (Table 19). El-Sheikh and Ulrich (1970) postulated that the mechanism for uptake of Na^+ in the presence of higher K^+ concentrations is absent in sugar beet plants up to the 10-leaf stage. Genotypic differences may be one reason for this discrepancy. Also, Leigh and Wyn Jones (1984) revealed that higher levels of Na^+ concentrations in young roots probably indicate that these are major vacuolar osmotica at this stage but then are replaced by sucrose as the root grows. Potentially, all salts could be replaced by sucrose as there is no a priori reason why they must contribute to vacuolar osmotic pressure. Lindhauer et al. (1990) reported that K^+, Na^+ and Mg^{2+} were the most important solutes in the leaves of sugar beet which played the main role for adjustment of the osmotic potential in leaves. However, the contribution of sucrose to osmotic potential in leaves was negligible. Also, Harvey and Dutton (1993) found that the physiological role and interrelations of the accumulations of the different solutes in storage roots are of interest because of the detrimental effects that non sucrose components have on the efficiency of sugar extraction during processing.

In case of our experiment concerned with K^+ substitution by Na^+ on growth of sugar beet grown in nutrient solution results indicated that all leaf and beet cation concentrations (except Na^+) reduced significantly due to increased K^+ substitution relative to 4.0 mM K^+ treatments (Table 21 and 22). It appears that increasing NaCl supply depressed the levels of K^+ and Ca^{2+} in leaves and beets and led to a gradual

increase in Na^+ and Cl^- concentrations. In older leaves Na^+ may replace K^+ not only in the vacuoles but also in the chloroplasts, thus releasing K^+ for specific functions in the meristematic and expanding tissues. Also, Na^+ was found to be taken up by the plant in response to K^+ deficiency, low K^+ plants absorbed Na^+ as a substitute cation for K^+ and as a result did not take up other metallic cations in appreciable quantities. When Na^+ was not supplied, low K^+ leaves acquired higher concentrations of Ca^{2+} and Mg^{2+} than did the control leaves. Na^+ may have substituted for K^+ in stomatal opening either directly, as an alternative cation to K^+, or indirectly by conserving K^+ supply. Analysis of variance show that different K^+ and Na^+ treatments had a strong effect on all cations measured in this study, but the differences among the cultivars are not statistically significant (Table 23). El-Sheikh and Ulrich (1970) found that Na^+ added to low K^+ solutions increased the Na^+ concentration but decreased the K^+ concentration of the petiole and young blades and increased the K^+ concentration of mature blades. This indicates K^+ redistribution from petioles to blades under the influence of Na^+. The addition of Na^+ to high K^+ solutions increased the Na^+ concentration of the leaf, but the increases were much smaller than in the low K^+ treatments. Kirkby et al. (1987) found that K^+ and Na^+ concentrations in dry matter progressively decreased during the season, from about 8% to 5% in the shoot and from about 5% to 1% in the storage root. Tissue water concentrations of $Na^+ + K^+$ also declined in the storage root during growth from ca. 200 to 50 mmol kg^{-1}, presumably because stored sucrose assumed an increasing role in cellular osmotic relations. However, tissue water concentrations in the shoot maintained less stable at 200 mmol kg^{-1} throughout the growth. Magat and Goh (1988) found that increasing yield as a result of NaCl and KCl applications may be due to K^+ or Na^+ with Cl^- component. Since, Cl^- was earlier shown to be an essential nutrient for plants (Johnson et al., 1957) and NaCl increases the root sugar yield, regardless of soil K^+ status. This has been attributed to the beneficial effect of Na^+ (Draycott and Bugg, 1982). High amounts of Na^+ and Cl^- accumulated in leaves and only a small fraction of these ions was translocated to the storage roots. The high total K^+ uptake required for increased root yields may be explained by the need of the crop to stimulate the translocation of photosynthates from leaves to the storage root (sink), aside from its role in photosynthesis. The yield responses to KCl applications may be due to both K^+ and Cl^-, while with NaCl applications, it may be attributed not

only to Cl^- but also to internal K^+ mobilization. Pantoja et al. (1990) postulated that the vacuole has major roles in pH and ionic regulation of the cytoplasm, turgor regulation of the cell, and the storage and retrieval of both organic and inorganic nutrients. The vacuolar membrane, the tonoplast, plays an important role in controlling the ionic concentrations in the cell, particularly for halophytes and salt-tolerant glycophytes that accumulate high concentrations of NaCl in their vacuole.

The results concerning the effects of various concentrations of Ca^{2+} on the growth of sugar beet show that Ca^{2+} concentrations of leaves and beets were reduced significantly by decreasing Ca^{2+} supply compared to 2.0 mM $CaCl_2$. In contrast to the Ca^{2+} concentrations, Mg^{2+} concentrations of leaves and beets increased significantly with decreasing Ca^{2+} supply. Cl^- and NO_3^- concentrations of leaves and beets decreased significantly due to decreased in the Ca^{2+} supply. PO_4^{3-} and SO_4^{2-} concentrations were increased by decreasing Ca^{2+} supply (Table 25). It is known that Ca^{2+} uptake may be reduced by the competitive effects of a high concentration of other cations such a K^+, Na^+ and Mg^{2+}. Marschner (1995) found that under field conditions in dry land areas with high transpiration rates, even an increase in Ca^{2+} concentration in the irrigation water cannot compensate for the decrease in root pressure-driven Ca^{2+} transport in the xylem to the shoot apex. There is now a considerable body of evidence to suggest that membranes contain selective K^+ channels which enable a selective uptake. Koyro (2000) found that K^+ is characterized by high mobility in plants. K^+ concentrations in cytosol are maintained in the range 100-200 mol m^{-3}. At high NaCl concentration, K^+, Mg^{2+} and Ca^{2+} concentrations decreased mainly in the vacuole and plants regulated the homeostasis of these elements in the cytosol.

5. 5 α-amino-N concentrations

In case of our experiment concerned with the effect of K^+ and Na^+ fertilization on the growth of sugar beet the results indicated that the higher values of α-amino-N concentrations of leaves and beets were observed at 3.9 g NaCl treatment, however, a lower α-amino-N concentrations were observed at 5.0 g KCl + 3.9 g NaCl for both cultivars. At two treatments of NaCl application α-amino-N concentrations of leaves and beets increased significantly at both harvests (Fig. 8 and 9). Our results are in agreement with the findings Daliparthy et al. (1994) who reported that a biochemical

interaction between Na^+ and K^+ operated only when adequate amounts of both were present. This interaction resulted in higher growth and increased tolerance to low external osmotic potential. Also, they reported that the influence of K^+ in sugar beet was assumed to be due to the reduction in α-amino-N content and in the alkalinity of the root. Theses results indicated a significant increase in sucrose content by 46% with the increase in K^+ supply.

Regarding, the effect of water stress and K^+ substitution by Na^+ on growth of sugar beet the data presented in this investigation show that leaf α-amino-N concentrations were slightly influenced by water stress and K^+ substitution. At the final harvest α-amino-N concentrations of leaves and beets were increased significantly at 50 and 75% K^+ substitution. It is interesting to note that drought had little effect on sugar concentration but the loss in sugar yield was exacerbated by an increase in storage root impurities, in particular α-amino-N concentrations (Table 12). Hanson and Hitz (1982) found that glycinebetaine accumulation, whether constitutive or salt induced, may be a specific adaptation for salt-tolerance in wild and cultivated membrers of the *Chenopodiaceae,* including *Beta* spp.

Result concerned with the effects of drought and heat on the growth of sugar beet show that the concentrations of α- amino-N concentrations of beets increased significantly at high temperature compared to low temperature for both water treatments (Fig. 46). Zayed and Zeid (1998) found that plants may increase its drought tolerance by decreasing osmotic potential by accumulation of solutes, which allows cell enlargement, plant growth and keeps open stomata and CO_2 assimilation under water stress. Many solutes may be used in osmotic adjustment including inorganic ions, such as Na^+, K^+ and Cl^- (Wyn Jones and Gorhan, 1983), and saccharides and amino acids, especially proline (Morgan, 1984).

The results concerning K^+ substitution by Na^+ on growth of sugar beet grown in nutrient solution revealed that the α- amino-N concentrations of beets increased significantly in the treatments with free $K^+ + Na^+$, low K^+ , low Na^+, and low $K^+ + Na^+$ treatments compared to 4.0 mM KCl treatment. Also, α- amino-N concentrations were

significantly increased in all treatments of K^+ substitution for cultivar Evita, and at 75 and 100%K^+ substitution for cultivar Sofie compared to 4.0 mM KCl (Fig. 61).

In case of our experiment concerned with effect of various concentrations of Ca^{2+} on the growth of sugar beet, the results indicated that α-amino-N concentrations of leaves and beets were significantly higher in the treatments of low Ca^{2+} supply compared to 2.0 mM $CaCl_2$ treatment (Fig. 70).

5. 6 Sugar yield

Yield of sucrose from sugar beet depends on three factors: (i) accumulation of total biomass, (ii) partition of dry matter into the roots and (iii) accumulation of sucrose in the roots. Crop growth is directly proportional to the amount of solar radiation absorbed by the foliage. While the efficiency by which absorbed radiation is converted into dry matter is fairly constant (*ca*. 10%), its value can be significantly lowered by moisture stress (Scott and Allen, 1978). Wyse (1979) found that, in sugar beet, sucrose is not hydrolyzed during transport from the source leaves into the vacuoles of parenchyma cells of the root. Sucrose uptake in sugar beet roots was liner between concentrations of 1 and 500 mM, occurred against a sucrose concentration gradient, and was sensitive to metabolic inhibitors. Saftner and Wyse (1980) reported that sucrose is actively transported into the vacuoles of sugar beet root discs in a manner consistent with an alkali cation/sucrose co- transport mechanism.

Results of our experiment concerned with effect of K^+ and Na^+ fertilization on the growth of sugar beet demonstrated that the sucrose concentrations (mg/g DW) of beets increased significantly in all treatments of K^+ and Na^+ fertilization **(**except 3.9 g NaCl) for both cultivars at the first harvest (Fig. 10). The sugar and white sugar yields increased significantly in all treatments of K^+ and Na^+ fertilization for both cultivars **(**except 5.0 g KCl application for cultivar Evita) at first harvest. At the second harvest both parameters increased significantly in all treatments only for cultivar Sofie (Fig. 12 and 13). A significant increase in sugar yield with the increase in K^+ supply may be due to an important role of K^+ in cell osmotic and turgor relations for all plants. Farley and Draycott (1974) earlier reported that both Na^+ and K^+ increased sugar concentration but the effect of Na^+ was progressively smaller when the K^+ dressing was increased, indicating a negative interaction between them. These two elements

appear to act differently from other fertilizers such as nitrogen, and many agronomic practices, which decrease (or increase), sugar percentage in fresh roots with little effect on sugar concentration in dry beets. Na^+ and K^+ are important impurities in sugar beet roots as they are water-soluble and hence decrease the amount of white sugar recovered in the factory process. Harvey and Dutton (1993) demonstrated that the high concentration of K^+ in beets limit the proportion of sucrose that can be extracted from the beet as crystalline sugar during factory processing. Eisa et al. (1999) found that sucrose concentrations were increased by increasing NaCl up to 2000 ppm, in late salt application, and up to 6000 ppm, in early salt application. The sugar percentage is usually in the range of 10-20%. Fertilizers have considerable effects on sugar percentage; some decrease it while others are beneficial. Where a fertilizer decreases sugar percentage but increases root yield it is important to know the "break-even" point where the increase in root yield is equated with decrease in sugar percentage, i.e. maximum sugar production by the crop. The sugar percentage of fresh roots is, of course, largely determined by the amount of water in the roots and climatic conditions before harvest.

The effect of water stress and K^+ substitution by Na^+ on sucrose concentrations (mg/g DW) of beets showed that sucrose concentrations were significantly higher under water stress compared to 70% WHC. At the first harvest higher sucrose concentrations were obtained in the treatments with 50% K^+ substitution. Also, sucrose concentrations increased significantly in all treatments of K^+ substitution by Na^+ compared to 100% KCl for both cultivars under water stress (Fig. 30). Sugar yield and white sugar yield were significantly increased in all treatments of K^+ substitution for both cultivars for both harvests at 70% WHC. Under water stress sugar and white sugar yields were significantly increased at 25 and 50% Na^+ substitution for two cultivars (Fig. 34 and 37). Although leaf area and evapotranspiration rate were increased by increasing of K^+ substitution by Na^+, a sugar yield depression was not observed at higher level of K^+ substitution in comparison to 100% KCl treatment. High concentrations of K^+ in beets limit the proportion of sucrose that can be extracted from the beet as crystalline sugar during factory processing. In this respect, Loomis and Worker (1963) reported that moisture stress reduced vegetative growth and

increased sucrose concentration and sucrose % fresh weight in the roots, but purity was not increased. The increase in sucrose concentration induced by wilting may be simply a result of lower moisture content of the root (due to dehydration or reduced water absorption relative to sucrose accumulation). However, if moisture stress limits sucrose utilization in growth processes to a greater extent than it reduces photosynthesis, as is the case with nitrogen deficiency, then the increase in sucrose concentration may be principally the result of more sucrose in the root. Also, Miller and Hang (1980) found that with a loam soil near the upper limit of available water at the start of the irrigation season, daily sprinkler irrigation rates could be reduced to 35 to 50% of estimated evapotranspiration rates without reducing sucrose yield. In sandy soil, sucrose yield increased with irrigation rate up to 100% estimated evapotranspiration. Hang and Miller (1986) revealed that on the loam soil, root sucrose concentration increased rapidly with time and the rate of increase was lower with adequate soil water than when it was limited. On the sandy soil, with limited water, root sucrose concentration increased to a maximum about of 8 weeks after irrigation treatments and then decreased. Sucrose concentration was significantly higher with limited than with adequate water until near harvest.

Sugar beet has been shown to tolerate mid and late-season plant water stress and this characteristic makes sugar beet a suitable crop for production with "limited" irrigation i.e. an irrigation amount less than that required to fully satisfy evapotranspiration. Water stress will almost invariably decrease fresh root weight, however, sucrose concentration, on a fresh weight basis; can be increased by dehydration of the root due to water stress. These effects on yield were mainly caused by dehydration of the beet tops and roots so sucrose production was scarcely affected even though only 70% of the normal irrigation water was applied. Limited irrigation reduced evapotranspiration rates because of drier surface soil and partial stomatal closure, thereby decreasing the rate of water extraction from the soil reservoir by the plant (Carter et al., 1980).

In case of our experiment concerned with the effect of drought and heat on the growth of sugar beet, results showed that sucrose concentrations (mg/g DW) increased significantly at high temperature under two water treatments for both cultivars (Fig.

47). In contrast sucrose concentrations, sugar yield and white sugar yield reduced significantly in all treatments for both cultivars (Fig. 51 and 52). It is clear that heat stress had a greater negative effect on yield and related characteristics than moisture stress. Analysis of variance show that heat was significantly affected the sucrose and fructose concentrations, whereas drought significantly affected the glucose concentrations only. Sugar yield and white sugar yield were significantly affected by temperature, water stress and genotypes whereas sucrose % FW was significantly affected by heat only (Table 20). The impact of drought has been recognized as a major cause of yield losses in sugar beet (Jaggard et al., 1998; Pidgeon et al., 2001). The best avenue for improvement of beet production in drought area is the development of varieties with increased drought tolerance (Ober and Luterbacher, 2002).

Results of our experiment concerned with the effect of K^+ substitution by Na^+ on growth of sugar beet grown in nutrient solution the results revealed that sucrose concentrations of beets decreased significantly at 0.1 mM NaCl treatment compared to free of K^+ and Na^+ and at 75% K^+ substitution compared to 4.0 mM KCl for both cultivars (Fig. 62). Sugar yield and white sugar yield increased significantly at 0.1 mM K^+ + 0.1 mM Na^+ compared to the free of K^+ and Na^+ treatment, whereas sugar yield and white reduced significantly at 100% K^+ substitution for both cultivars. These two parameters, however, were not significantly affected at 25, 50 and 75% K^+ substitution compared to the 4.0 mM K^+ treatment (Fig. 66 and 67). The increase in sucrose concentration and sugar yield when Na^+ is added to high K^+ solutions suggests the possibility that Na^+ might be involved in sugar formation directly by its effects on photosynthesis or indirectly by leaf blade enlargement. However, the percentage sucrose values were less than those of plants in a medium containing a high K^+ and Na^+ concentration. Our results are in agreement with the findings of Evans and Sorger (1966) who found that reducing sugars accumulate in plants that are low in K^+. When K^+ is supplied the sugar content declines as tissue K^+ increases. However, El-Sheikh and Ulrich (1970) revealed that the high sucrose concentration in the leaves in the presence of Na^+ might facilitate phloem loading and transport of sucrose into the storage root and result in higher sucrose concentration in this "sink" in comparison to

K^+ only. Marschner (1995) found that sugar beet growing in nutrient solutions rich in Na^+ exhibit stimulated leaf growth. On the other hand, emphasis on K^+ in the nutrient solution favors growth and sucrose accumulation of the storage root (Lindhauer and Haeder, 1987). Additionally, Na^+ increases the sucrose concentration and sugar yield of the storage roots even when the plants are grown in a high K^+ solution. When Na^+ supplied simultaneously, synergetic effects are present only at low K^+ supply.

In case of our experiment concerned with the effect of Ca^{2+} deficiency on the growth of sugar beet cultivar the results demonstrated that sucrose concentrations, sugar yield, and white sugar yield were significantly decreased by reduction of Ca^{2+} supply compared to 2.0 mM $CaCl_2$. Colmer et al. (1994) reported that in salt-treated plants Ca^{2+} seems to be beneficial in maintaining a high pH-gradient between cytoplasm and vacuole and sustains the putative driving force for Na^+ transport from the cytosol into the vacuole via a channel as well as levels of cytoplasmic K^+, cytoplasmic and vacuolar phosphate. Ca^{2+} can alleviate the inhibitory effect of NaCl on plant growth by maintaining plasmamembrane selectivity of K^+ over Na^+ (Zhong and Läuchli, 1994).

6 Summary

In this investigation the effect of K^+ and Na^+ fertilization and the substitution of K^+ by Na^+ on the growth of two cultivars (Evita and Sofie) of sugar beet (*Beta vulgaris* L.) was studied in soil culture and nutrient solution experiments. In addition, the effects of drought and heat were investigated on the growth and quality of sugar beet too.

The most important results obtained from this investigation can be summarized as followed:

1. A positive effect of Na^+ fertilization or substitution of K^+ by Na^+ on growth of sugar beet crop was observed for both cultivars at both harvests. However, the plant growth was significantly decreased by water stress or Ca^{2+} deficiency treatment. On the other hand, yield of sugar beet was more affected by heat treatment than drought treatment.
2. The results suggest that K^+ can be substituted by Na^+ in some metabolic processes of sugar beet grown in the soil, if sugar beet is supplied with sufficient K^+. On the other hand, if K^+ application is limited during a K^+ substitution by Na^+, Ca^{2+} uptake will be decreased, since we assume that Na^+ blocks the unspecific channel for Ca^{2+} uptake. We assume that the possible substitution of K^+ by Na^+ is limited by the Ca^{2+} nutrition of sugar beet.
3. Leaf area was significantly decreased under water stress, whereas it was significantly increased by increasing K^+ substitution by Na^+.
4. Na^+ increased the evapotranspiration at high water availability (70% WHC) than plants supplied with K^+, but this was not observed under water stress (40% WHC) conditions. Transpiration and transpiration rate of plants in nutrient solution were significantly increased by increasing of K^+ substitution by Na^+, whereas water use efficiency was significantly decreased. Water consumption increased significantly, but water use efficiency was significantly reduced at high temperature compared to low temperature.

5. K^+ concentrations of leaves and beets were significantly decreased in all treatments of K^+ substitution by Na^+. However, K^+ concentrations were significantly decreased at low K^+ supply. On the other hand, Na^+ concentrations were significantly increased due to Na^+ application at two levels of NaCl, and in all treatments in which K^+ was substituted by Na^+.

6. Beet α-amino-N concentrations were significantly increased at higher level of NaCl fertilization and in all treatments of K^+ substitution by Na^+, or by decreased Ca^{2+} application. Nevertheless, the α-amino-N concentrations of beets were slightly influenced by drought and heat stress.

7. Sucrose concentrations of beets was significantly higher in all treatments in which K^+ was substituted by Na^+, and under drought and heat stress treatments. Lowering Ca^{2+} supply, however, significantly reduced the concentration of sucrose.

8. The sugar yield was significantly increased in all treatments of K^+ substitution by Na^+. Nevertheless, both NaCl applications and decreasing calcium supply significantly reduced sugar yield.

7 Zusammenfassung

Die Zuckerrübe ist die wichtigste Zucker produzierende Pflanze in den gemäßigten Regionen der Welt. In der Mittelmeerregion erfordert eine befriedigende Zuckerrübenproduktion eine Ergänzungsbewässerung. In den letzten Jahren ist Trockenstress ein Hauptbegrenzungsfaktor der Zuckerrübenproduktion geworden. K^+ spielt eine wichtige Rolle in der Stomataregulation und im Wasserverbrauch. Bei einer begrenzten Wasserversorgung wirkt Na^+ positiv auf die Trockentoleranz der Zuckerrübe. Obgleich die Entwicklungsphysiologie der Pflanze erforscht worden ist, ist wenig über die Faktoren bekannt, die den Zuckergehalt der Wurzel oder die physiologischen Prozesse regeln, welche die Pflanze zu Veränderungen veranlassen.

Ziel der vorliegenden Untersuchung war es, den Effekt der K^+- und Na^+-Düngung und den Einfluss von Wasserstress und der Substitution von K^+ durch Na^+ auf das Wachstum von zwei Zuckerrübensorten (Beta vulgaris L. cv. Evita und cv. Sofie) in Boden- und Nährlösungskultur zu studieren. In einem weiteren Experiment wurden die Effekte von Trockenstress und Hitze auf das Wachstum und die Qualität der Zuckerrübe untersucht.

7.1 Untersuchung der Effekte von K^+- und Na^+-Düngung auf das Wachstum der Zuckerrübe

Dieses Experiment wurde in großen Mitscherlich-Gefäßen mit 15,0 kg Boden pro Gefäß durchgeführt. Der Boden stammt aus Kleinlinden, einer Region in Hessen, Deutschland. Der Boden wurde mit $MgCO_3$, $Ca(H_2PO_4)_2$ + $CaSO_4$ (Superphosphat), NH_4NO_3 und H_3BO_3 mit einer Rate von 0,133 bzw. 1,91, 0,38 und 0,003 g/kg Boden, gemischt. Sechs Behandlungen, d.h. 2,5 g KCl, 5,0 g KCl, 2,0 g NaCl, 3,9 g NaCl, 2,5 g KCl + 2,0 g NaCl und 5,0 g KCl + 3,9 g NaCl wurden durchgeführt.

Die Gefäße wurden in einer randomisierten kompletten Blockanlage angeordnet, mit 10-facher Wiederholung pro Variante. Zuckerrübensamen (6 Samen Gefäß$^{-1}$) wurden am 2. Mai 2000 ausgesät. Nach der Aussaat wurde der Boden mit destilliertem Wasser bewässert, um den Feuchtigkeitsgehalt bei 60-70% der maximalen Wasserhaltekapazität (WHK) zu halten. Ein Monat nach der Aussaat wurden die Sämlinge ausgedünnt, so dass pro Gefäß eine Pflanze übrig blieb, und 0,19 g NH_4NO_3

kg^{-1} Boden wurden in flüssiger Form hinzugefügt. Die erste Ernte der Pflanzen fand 2 und die zweite Ernte 6 Monate nach der Aussaat statt.

Die wichtigsten Resultate dieser Untersuchung können wie folgt zusammengefasst werden:

- Na^+ hat einen positiven Effekt auf den Wasserhaushalt der Zuckerrübe. Der positive Effekt von Na^+ hängt wahrscheinlich mit der verbesserten Trockenresistenz bei limitierter Wasserversorgung zusammen.

- Bei der ersten Ernte wurden die Rübenfrisch- und Trockenmasse signifikant bei allen Behandlungen im Vergleich mit 2,5 g KCl erhöht. Bei einer 2,0 g NaCl-Variante der Sorte Evita waren Rübenfrisch- und Trockenmasse bei der zweiten Ernte signifikant verringert. Für die Sorte Sofie war die Rübenfrisch- und Trockenmasse signifikant bei allen Varianten erhöht im Vergleich zu der 2.5 g KCl-Variante. Ein positiver Effekt der NaCl-Düngung auf die Rübentrockenmasse konnte bei beiden Sorten beobachtet werden.

- Die höheren α-Amino-N-Konzentrationen der Blätter und Rüben wurden bei der 3,9 g NaCl-Behandlung beobachtet, jedoch wurden niedrigere α-Amino-N-Konzentrationen bei der 5,0 g KCl + 3.9 g NaCl-Variante für beide Sorten beobachtet.
- Die Saccharosekonzentrationen (mg/g DW) der Rüben erhöhten sich signifikant bei allen Behandlungen der K^+- und Na^+-Düngung für beide Sorten aus der ersten Ernte. Die Zucker- und der Weißzuckerertrag erhöhten sich signifikant bei allen Varianten der K^+- und Na^+-Düngung aus der ersten Ernte. Bei der zweiten Ernte erhöhten sich beide Parameter nur für die Sorte Sofie bei allen Behandlungen erheblich.

7.2 Effekte von Wasserstress und K^+-Substitution durch Na^+ auf das Wachstum von zwei Zuckerrübensorten

Dieses Experiment wurde in großen Mitscherlich-Gefäßen mit 15,0 kg Boden pro Gefäß durchgeführt. Der Boden stammt aus Kleinlinden, einer Region in Hessen, Deutschland. Der Boden wurde mit $MgCO_3$ (0,133 kg^{-1} Boden), $Ca(H_2PO_4)_2$ + $CaSO_4$ (Superphosphat, 1,91 kg^{-1} Boden), NH_4NO_3 (0,38 kg^{-1} Boden) und H_3BO_3 (0.003 kg^{-1} Boden) gemischt. In diesem Versuch gab es 4 Varianten, wobei jeweils 0, 25, 50, und

75% K^+ durch Na^+ substituiert wurden, unter zwei unterschiedlichen Wasserbehandlungen von 70 und 40% der WHK.

- Bei einer 70%igen WHK wurde die Rübenfrischmasse mit steigender Substitution des K^+ durch Na^+ erhöht. Dieser Effekt war bei 40% der WHK Variante nicht zu beobachten.

- Der Weißzuckerertrag ist nur bei 70% der WHK in allen Varianten, bei denen K^+ durch Na^+ ersetzt wurde, angestiegen.

- Blattoberfläche, Wasserverbrauch und Zuckerertrag wurden durch die Erhöhung des Ersatzes von K^+ durch Na^+ erhöht bei 70% der WHK, dieses wurde jedoch nicht bei 40% der WHC beobachtet.

- In der ersten Ernte war die Evapotranspiration bei 70% der WHK höher als unter 40% WHK. Bei der Na^+-Applikation im Vergleich zu der K^+-Applikation wurde die Evapotranspiration und Evapotranspirationsrate unter Wasserstress erheblich verringert. Zusätzlich erhöhte sich die Wassernutzungseffizienz beider Sorten signifikant bei 50% und 75% der K^+-Substitution.

- Bei beiden Sorten erhöhte sich unter Wasserstress die Saccharosekonzentration signifikant, und zwar in allen Behandlungen der K^+-Substitution durch Na^+ im Vergleich zur 100% K^+-Variante.
- Bei 70% der WHK wurden Zucker- und Weißzuckerertrag bei allen Behandlungen der K^+-Substitution bei beiden Sorten signifikant erhöht. Unter Wasserstress wurde der Zucker- und Weißzuckerertrag nur bei 25 und 50% Na^+-Substitution deutlich erhöht.

7.3 Einfluss von Trockenheit und Hitze auf die Evapotranspiration von zwei Zuckerrübensorten

Die zwei Zuckerrübensorten wurden in zwei Klimakammern mit zwei unterschiedlichen Temperaturen in kleinen Mitscherlich-Gefäßen mit 6,0 kg Kleinlindener Boden angezogen. Darüber hinaus wurden zwei verschiedene Wasserversorgungen getestet. Die Pflanzen wurden nach 10 Wochen geerntet.

Die Ergebnisse zeigen:

- Eine Verminderung der Pflanzenfrischmasse bei erhöhter Temperatur im Vergleich zur optimalen Temperatur. Durch zusätzlichen Wasserstress wurde die Pflanzenfrischmasse weiter vermindert.

- Die Rübenfrischmasse war bei hohen Temperaturen unter Trockenstress im Vergleich zur Variante mit optimaler Temperatur reduziert.

- Bei hoher Temperatur war die Rübenfrischmasse niedriger, verglichen mit der optimalen Temperatur. Durch zusätzlichen Wasserstress wurde die Rübenfrischmasse weiter reduziert.

- Die Evapotranspirationsrate bei hoher Temperatur war höher als bei optimaler Temperatur. Es war kein signifikanter Effekt zwischen zwei Wasserbehandlungen zu beobachten.

- Infolgedessen nahm die Wassernutzungseffizienz deutlich in der Hitzevariante ab.

- Obwohl die Saccharosekonzentration in der Rübe infolge der hohen Temperaturen anstieg, nahm der Weißzuckerertrag in den Rüben der Hitzevariante deutlich ab.

- Erhöhte Respiration unter Hitzestress war nicht die Ursache für die Ertragsminderung.

7.4 Effekte von K^+-Substitution durch Na^+ auf das Wachstum von zwei Zuckerrübensorten in Nährlösung unter natürlichen Bedingungen

In diesem Versuch wurden alle Pflanzen in voller Nährlösung über einen Zeitraum von zwei Wochen angezogen. Danach wurden sie mit verschiedenen K^+- und Na^+-Konzentrationen in der Nährlösung behandelt. Eine Variante enthielt weder K^+ noch Na^+, den anderen Varianten wurden niedrige K^+- oder Na^+-Konzentrationen oder einer Kombination aus beiden gegeben. Als Kontrolle diente eine Variante mit 4 mM K^+. Weiterhin wurden in 4 Varianten 25, 50, 75 beziehungsweise 100% des K^+ durch Na^+ ersetzt.

- Das Pflanzenwachstum erhöhte sich bei der 25, 50 und 75%igen K^+-Substitution. Bei 100%iger K^+-Substitution durch Na^+ ging das Wachstum, im Vergleich zur Kontrolle mit 100% K^+, stark zurück.

- Der Weißzuckerertrag war in der Variante ohne K^+ und Na^+, in den anderen Varianten mit niedriger Konzentration von K^+ oder Na^+ und in der niedrigen Kombinationsvariante von K^+ und Na^+, im Vergleich zur Kontrollvariante (4 mM KCl) reduziert. Es waren keine signifikanten Unterschiede zwischen 25, 50 und 75% K^+-Substitution zu beobachten. Der Weißzuckerertrag bei 4 mM NaCl im Vergleich zu 4 mM KCl (Kontrolle) war vermindert. Das galt für die Sorte Evita genau so wie für die Sorte Sofie.

- Obgleich K-Mangelsymptome auch auf höherem Niveau der Substitution von K^+ durch Na^+ nicht beobachtet wurden, war das Wachstum der Zuckerrüben reduziert. Substitution von K^+ durch Na^+ führte zu suboptimalen Ca-Konzentrationen in den Rübenblättern.

- Na^+ kann K^+ in einem hohen Ausmaß in der Zuckerrübe substituieren.

7.5 Einfluss von Ca-Mangel auf das Wachstum von Zuckerrüben

- In den Ca-Mangelvarianten verringerte sich die Frisch- und Trockenmasse der Blätter und Rüben erheblich.

- Die Ca^{2+}-Konzentration in den Ca-Mangelvarianten war im Vergleich zur 2 mM $CaCl_2$-Variante reduziert. Im Gegensatz zu den Ca^{2+}-Konzentrationen erhöhten sich, mit der Verringerung der Ca^{2+}-Versorgung, die Mg^{2+}-Konzentrationen der Blätter und Rüben erheblich.

- Die Herzblätter waren von der Spitze ausgehend deformiert und vertrocknet und zeigten eine schwarzbraune Verfärbung.

- α-Amino-N-Konzentrationen in Blättern und Rüben waren in den Ca-Mangelvarianten im Vergleich zur 2,0 mM $CaCl_2$-Variante deutlich höher.

- Saccharosekonzentrationen, Zuckerertrag und Weißzuckerertrag verringerten sich signifikant in den Ca-Mangelvarianten im Vergleich zur 2,0 mM $CaCl_2$-Variante.

Folgende Schlussfolgerungen lassen sich ziehen:

1. Ein positiver Effekt von Na^+- Düngung oder Substitution von K^+ durch Na^+ auf das Wachstum der Zuckerrübe wurde für beide Sorten bei beiden Ernten

beobachtet. Jedoch wurde das Wachstum erheblich durch Wasserstress oder durch Ca-Mangel verringert. Andererseits wurde der Ertrag der Zuckerrübe eher durch Hitze als durch Wasserstress beeinflusst.

2. Die Ergebnisse zeigen, dass K^+ durch Na^+ in einigen metabolischen Prozessen der Zuckerrübe ersetzt werden kann, wenn die Zuckerrübe mit genügend K^+ ernährt wurde. Andererseits, wenn das K^+-Angebot während einer K^+-Substitution durch Na^+ begrenzt ist, wird die Ca^{2+}-Aufnahme verringert, da vermutet wird, dass Na^+ die Ca^{2+}-Aufnahme durch eine Blockade der unspezifischen Ca^{2+}-Kanäle hemmt. Es ist anzunehmen, dass die mögliche Substitution von K^+ durch Na^+ durch die Ca^{2+}-Ernährung der Zuckerrübe begrenzt wird.

3. Die Blattfläche war signifikant unter Wasserstress verringert, während die Blattfläche signifikant durch die Verstärung der K^+-Substitution durch Na^+ erhöht wurde.

4. Na^+ erhöhte die Evapotranspiration (ET) bei hoher Wasserverfügbarkeit (70% der maximalen Wasserkapazität) im Vergleich zu Pflanzen, die mit K^+ gedüngt wurden. Dies konnte nicht unter Trockenstressbedingungen (40% der maximalen Wasserkapazität) beobachtet werden. Transpiration und Transpirationsrate der Pflanzen in der Nährlösung wurden erheblich durch die Erhöhung der K^+-Substitution durch Na^+ erhöht, während die Wassernutzungseffizienz erheblich verringert wurde. Der Wasserverbrauch erhöhte sich erheblich. Die Wassernutzungseffizienz wurde aber im Vergleich zur niedrigen Temperatur bei hoher Temperatur verringert.

5. Die K^+-Konzentration der Blätter und Rüben aller Behandlungen der K^+-Substitution durch Na^+ war erheblich verringert. Jedoch war die K^+-Konzentration bei niedriger K^+-Versorgung verringert. Andererseits war die Na^+-Konzentration signifikant durch die Na^+-Applikation bei zwei Behandlungen von NaCl und in allen Behandlungen, in denen K^+ durch Na^+ substituiert wurde, erhöht.

6. Die α-Amino-N-Konzentration der Rüben wurde durch höhere NaCl-Düngung sowie in allen Behandlungen der K^+-Substitution durch Na^+ oder durch verringerte Ca-Aufnahme erhöht. Dennoch wurde die α-Amino-N-

Konzentration der Rüben etwas durch Trockenstress und hohe Temperatur beeinflusst.

7. Die Saccharosekonzentration der Rüben war in allen Behandlungen der Substitution von K^+ durch Na^+ unter Trockenstress und bei Hitze erheblich erhöht. Das Senken der Ca-Versorgung verringerte die Saccharosekonzentration.

8. Der Zuckerertrag wurde signifikant in allen Behandlungen der Substitution von K^+ durch Na^+ erhöht. Dennoch verringerten beide NaCl-Anwendungen und eine abnehmende Ca-Versorgung erheblich den Zuckerertrag.

9. Obgleich K-Mangelsymptome nicht auf höherem Level der Substitution von K^+ durch Na^+ beobachtet wurden, nahm die Ca^{2+}-Konzentration in den Behandlungen ab.

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ACKNOWLEDGMENT

I wish to extend my heartiest thanks to all who have contributed to the successful completion of the present study. I would like to express my deep appreciation and sincere gratitude to Prof. Dr. Sven Schubert, Institute of Plant Nutrition, Justus Liebig University, Giessen, Germany, for his fruitful supervision, unfailing guidance and continuous help that made this work possible.

High appreciation and deepest thanks are extended to Prof. Dr. Diedrich Steffens, Institute of Plant Nutrition, Justus Liebig University, Giessen, Germany for his unreserved supervision and guidance during the period of the study.

I am indebted and very grateful to Prof. Dr. Karl-Heinz Kogel, Institute of Phytopathology and Applied Zoology, Justus Liebig University, Giessen, Germany for his valuable suggestion to further improve the manuscript.

All members of the Examining Board deserve sincere thanks for devoting their precious time before and during the examination.

Sincere gratitude is due also to the Government of Arab Republic of Egypt for the provision of necessary financial support throughout the period of my academic training.

I wish to express my sincere thanks and gratitude to all members of Institute of Plant Nutrition, Giessen and Agronomy Department, Faculty of Agriculture, Assiut University who in one way or another contributed to the successful accomplishment of this work.

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